An assessment of indoor environmental quality and occupant physiological factors for the development of an enhanced post occupancy evaluation model (ePOE)

By

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Research & Thesis Declaration

I confirm that the enclosed content is my own work and the use of all material from other sources has been acknowledged.

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4th July 2018

Abstract

Indoor environment quality (IEQ) has with previous research been proven to affect occupant health, well - being and productivity. Our research however seeks to understand uniquely these IEQ factors and the possible relationship between the occupant and building environment. The intelligent design & operation of commercial offices offers a potential opportunity to close the building energy performance gap, but only if we understand discretely the relationship between the occupant and building workplace. Using sensory feedback devices worn by the occupant, discrete IEQ measurements and Post Occupancy Evaluation (PoE) responses, we focus upon analysing two workplaces in Bracknell and Manchester. Initial research suggests a lack of defined IEQ standards exists within the UK, therefore this research seeks to explore opportunities to develop such guidance using field and analytical review.

The research considers the physiological effects of the built environment across x8 volunteers focussing upon stress measurements, skin temperatures, heart rate, breathing rate and blood oxygen level. The hypothesis of research proposes, that the built environment has specific effects on an individual's physiological responses inclusive of subjective and objective responses gained from surveys and interviews developed to test current awareness of these relationships and their importance.

The research concludes that these relationships are periodic and seasonal, demonstrating daily and weekly patterns exist across individual samples at x2 UK locations, whereby the individual volunteer's responses can be considered to correlate across the analysed data.

Keywords:

Intelligent; Health; Well- being; Standards; Evaluation; Post Occupancy; IEQ; Performance; Satisfaction; Occupant; Analytic; Hierarchy.

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This Thesis is dedicated to Rita Middlehurst (Mum) and Janet Simmons (Mother-in-Law) who both sadly passed away during the last 8-months not seeing these achievements. You are very much missed.

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1) - An investigation into the effects of workplace designs upon occupant well-being, satisfaction and performance Gary Middlehurst, Prof. Runming Yao, Prof. Derek Clements-Croome– CIBSE Technical Symposium, Edinburgh, UK, 14-15 April 206.

2) - BSRIA Presentation – Strategic Portfolio Management – The challenges of in-house v outsourced hard FM – 22nd April 2015

3) - BSRIA Presentation – Health & Well-being – Connecting occupants to buildings, 15th January 2016.

4) - A preliminary study on post-occupancy evaluation of four office buildings in the UK based on the Analytic Hierarchy Process
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Chapter 1 - Introduction

Indoor Environmental Quality (IEQ) has from previous research been proven to affect occupant health (Bluyssen et al 2015) well-being (BCO 2015) and productivity (CBI Report 2015) This research seeks to extend existing knowledge by understanding further the unique nature of these IEQ factors and the relationship between occupant health, well-being and workplace performance factors. Previous research has tended to focus upon determining IEQ weighting schemes, comfort levels and assessing the productivity of workers. This research critically assesses workplace and physiological factors to create an enhanced post occupancy evaluation (e-POE) method.

1.1 The Property Investment Horizon

The UK commercial real estate sector has over many years, developed into a complex mixture of integrated relationships with each recognised stakeholder possessing quite different investment and operational needs. With an industry sector controlled and fundamentally driven by financial investment and return, it is therefore not un-surprising to see many building projects focussed towards short-term investment, rather than the needs of building occupants. This strategic dilemma faced by an industry desperate to expand and to promote new forms of sustainable intelligent buildings, manifests as a consequence of old fashioned investment strategies constrained by initial capital investment, but it is also as a consequence of ignoring proven whole life cycle value (WLCV) principles which offer longer-term holistic returns both to the economy investor and society as a whole.

With commercial real estate professionals at last beginning to realise that occupier needs and demands are now becoming strategically important, it is the more complex aspect of stakeholder engagement that needs to be developed.

With the UK commercial property industry (Fig.1) estimated to be worth £647bn in 2013, it is not unreasonable to suggest that property investment is an integral part of our economy. From our pensions to taxation, our economic reliance upon property investment is fundamental the UK economy and covers many different forms of property strategies. From speculative developments, to end-user designed workplaces, and through to regeneration type projects, each strategy comprises of different investment and return requirements from their eventual investors.

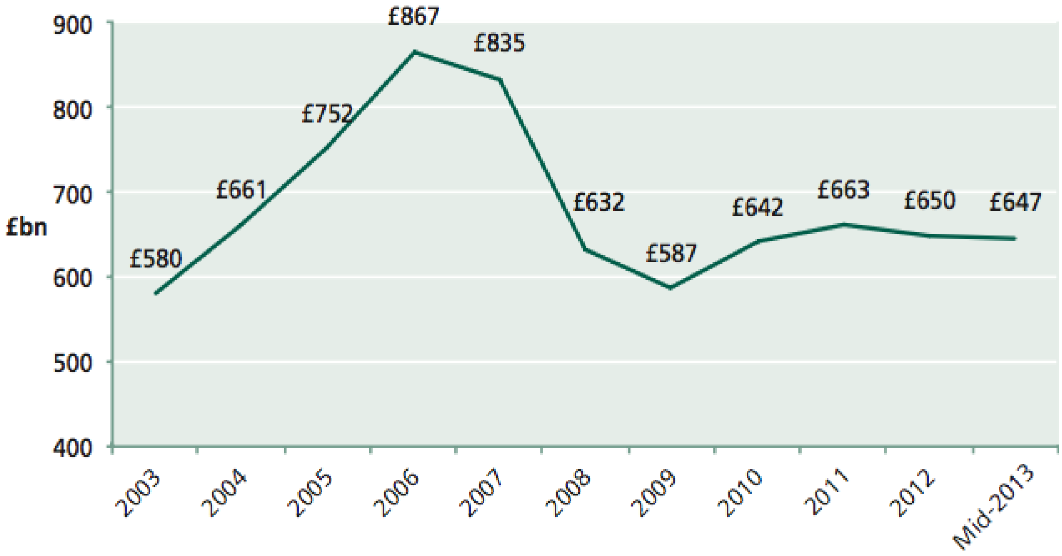


Fig.1 UK Commercial Property Values 2003 – 2013
Source: PMRECON - IPF Research Programme 2011–2015 (published - March 2014) [4]

The commercial property sector is divided into three main and very discrete elements; ***retail*** type stores***, office*** buildings and ***industrial*** type buildings. These three elements are estimated to cover approximately 679million (m^2) of floor-space and have the combined capacity to generate £50.3bn (£74/m^2)[1] of rental income per annum. With such economic impact available, perhaps an opportunity exists to un-lock how we think about buildings and to incorporate health & well-being of occupants as a real societal issue.

Breaking down these property sectors into their respective market share, it can be seen that ***retail*** property accounts for 45% of the total capital value (p.a.), ***offices*** account for 28%, ***industrial*** properties account for 18% and ***other*** commercial type buildings account for the remaining 9%. The UK commercial office horizon as (Table-1) is estimated to occupy 108million (m^2) of floor space, and has a potential rental value of circa £13.9bn - based upon an average (UK) rental rate of £128/m^2. Interestingly within a UK regional context, London accounts for approximately 2/3^rds^ of this total with a capital value of £114bn and a potential rental income of £4.6bn[1]. The importance of understanding the scale and value of the UK property industry provides an opportunity to promote the selection of appropriate investment options when designing buildings to achieve the highest performance return for the building and the eventual occupant.

	Retail	Offices	Industrial	Other	Total
Capital value (£bn)	£293	£183	£117	£54	£647
Change since 2003	13%	26%	–11%	23%	11%
Rental value (3bn)	£20.6	£13.9	£12.1	£3.8	£50.3
Rental value per sq m	£133	£128	£32	£100	£74
Floorspace (million sq m)	154	108	379	38	679
Yield	7.0%	7.6%	10.4%	7.0%	7.8%
Capital value London (£bn)	£78	£114	£16	£15	£223
Change since 2003	50%	59%	-7%	36%	47%
London as % of UK	27%	62%	13%	28%	34%
Capital value Rest of UK (bn)	£215	£69	£101	£39	£424
Change since 2003	4%	–6%	–12%	18%	–1%

Source: PMRECON

Table 1 – UK Commercial Property Financial Outlook - *Source: IPF Research Programme 2011–2015 (published - March 2014) [1] – Gross Values.*

If we take a holistic UK commercial office view, the industry tends to exist in two distinct forms; those who own, occupy and operate their buildings directly; and those who as tenants lease or rent their space on a termed basis. With total UK investor funding estimated at £364bn (56% of the total capital value), and commercial offices accounting for £145bn or 40% of the total investment value (Fig. 2), then perhaps we have an opportunity to demonstrate a best value approach to convince investor stakeholders of the reality of whole life cycle value (WLCV) principles. When we consider how the investment horizon is supported, we begin to see how stakeholder engagement and management becomes a difficult task and one that is seldom coordinated. The property stakeholder diagram (Fig.3) indicates the key participants supporting the property industry, the breadth of those involved and the lack of any single coordinating role. Interestingly the vast majority of these stakeholders are considerably removed from the long-term operational performance of buildings, or indeed in any form of relationship with the building occupant. It is therefore essential as an industry that we consider this dis-connection when assessing the future for promoting health & well-being across the UK property sector.

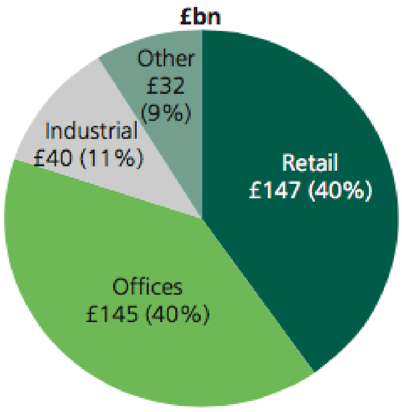


Fig. 2 – Investment Values per property sector *- Source: IPF Research Programme [1]*

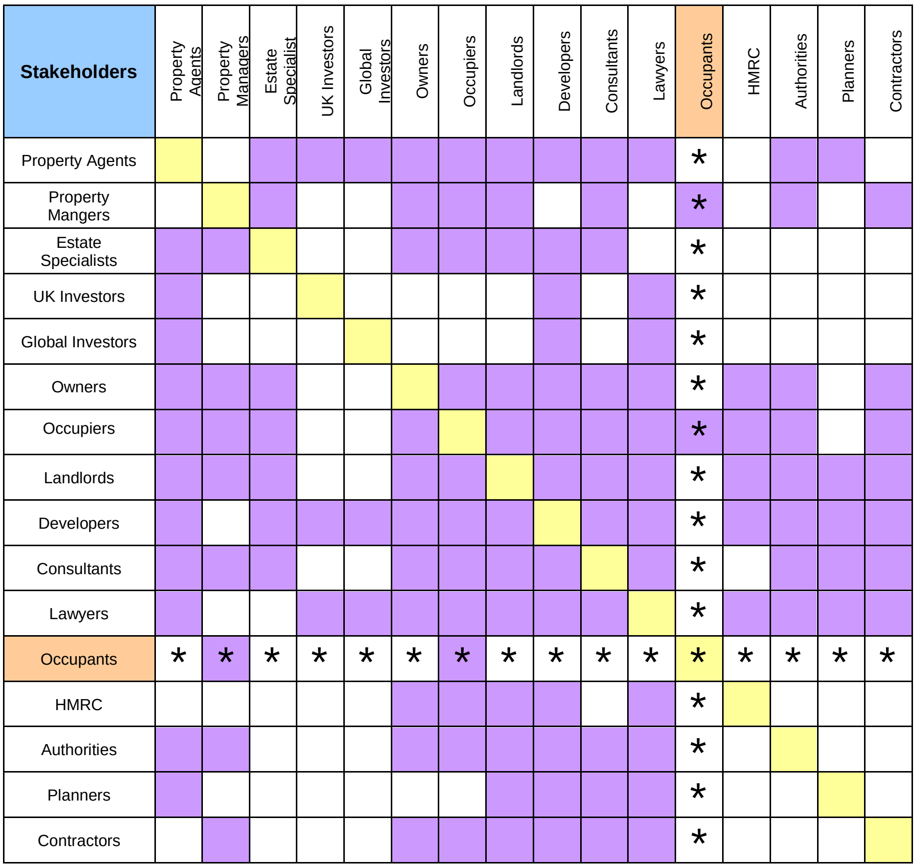


Fig. 3 – Property Key Stakeholder Relationship Matrix

Further complexity stems from the diversity of participating investors and their relevant investment criteria. Table 2 indicates the various types of investors within the UK property sector, their investment values, and the fluctuations in investment strategy since 2003.

Investor Types	£bn (Mid 2013)	% share (£364bn)	% change since 2013
Insurance funds	£41bn	11.%	(-29%)
Segregated Pension funds	£30bn	8.2%	(-1%)
UK & Channel Island domiciled investment schemes	£59bn	16.2%	118%
UK REITS and listed property companies	£52bn	14.4%	30%
Private property companies	£50bn	13.7%	0%
Traditional estates and charities	£16bn	4.4%	18%
Private investors	£10bn	2.7%	27%
Other	£18bn	4.9%	23%
Overseas	£88bn	24.2%	113%
Total	£364bn	100%	27%

***Table 2 – Property Sector Key Investor Types -** Source: IPF Research Programme 2011–2015[1]*

With such commercial dynamics involved across the property sector and the lack of WLCV knowledge available to the investors, we face the real dilemma of how to strategically change the design, construction and operation of our next generation of buildings when aspiring to provide higher levels of occupant satisfaction, performance, health and well-being.

The opportunity to affect investment decisions and to create a more sustainable investment strategy is now unique. The lack of occupant focus from key property stakeholders and the differing dynamic relationships should be seen as a major investment opportunity to drive better preforming buildings. A recent (2014) report by Cushman & Wakefield [2] positioned London as the most expensive city to own and operate a property - 48% more expensive than Hong Kong ranked No.2 (Fig. 4). Unfortunately, there is no available evidence to suggest this cost differential is as a result of sustainable investment or better buildings, however, what is interesting is the significantly higher operational costs here in the UK which is nor driving better buildings. When we consider the global property cost ratings, we need to ask ourselves why such a disparity exists, particularly when the office work task is so very similar even globally. To what value are we associating with these costs?

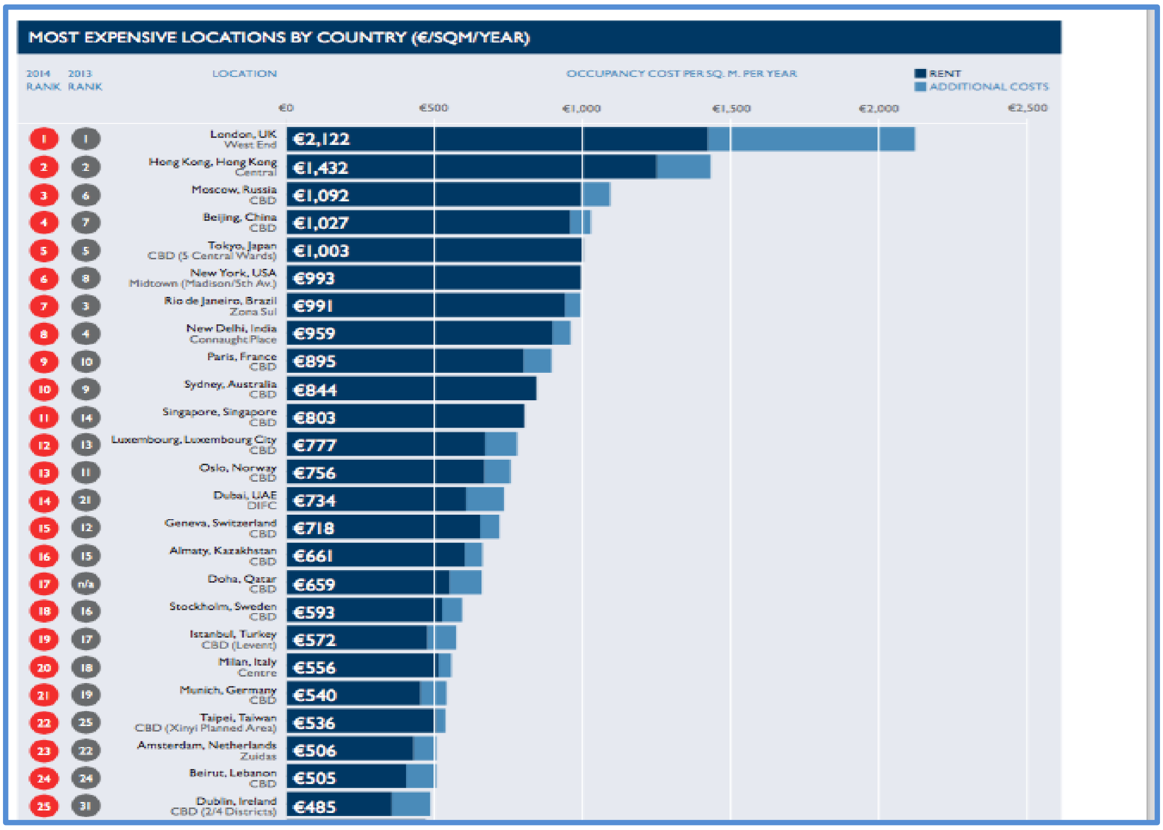


Fig. 4 – Global Property (Office) Operating Costs (Top 25 most expensive)
Source Cushman & Wakefield: Office Space Across the World 2014

UK and global property agents Lambert Smith Hampton (LSH) published within their latest report "Activating the Workplace – Office Market 2015"[3], that occupiers are now becoming more discerning regarding their workplace environments. They claim businesses are now enhancing their workplaces to communicate the culture of their organisation, but they are now also seeking to enhance occupant health, well-being and productivity as a key business performance driver. As occupiers seek to use their space more efficiently and effectively, the LSH report also suggests that investors will now start to search for the value added property investment opportunity. This new focus on well-being, space and efficacy is a realisation that workplaces now play a vital role in retaining and attracting new staff, with the most progressive firms moving **"Beyond the Workplace"** into the next generation of sustainable and productive workplaces.

LSH continue in the same report, that landlords and/or property owners who are in tune with well-being and the principles of "Beyond the Workplace", now stand the best chance of maximising their property and workplace investments. Investigating other existing high quality spaces, businesses and a review of existing surveyed occupant feedback, LSH also noted a number of other key property aspects relevant to creating a "Beyond the Workplace" (BtW) environment.

1. Enhancing the general available amenities
2. High quality and shared spaces
3. Spatial flexibility and adaptability
4. Sustainable design and operations.
5. The building as a community

} **= Beyond the Workplace**

These new and proposed property facets, are indeed important, however, businesses must continue to maximise the space they occupy, and to manage their annual operational costs efficiently. Occupancy densities for example are directly related to operational revenue expenditure, however, occupant densities can significantly impact productivity and performance. Delivering LSH's suggested BtW aspects may therefore conflict with some of these business objectives and therefore it is vital that adequate research is established to assess the complicate interaction of IEQ factors and occupant responses.

1.2 Property Market View

The UK property sector remains under relentless pressure to exist sustainably, however, it operates within significant business and regulatory constraints. These pressures are not only pushing organisations to improve cost to income ratios to satisfy shareholder demands, but they are now driving lower available capital and revenue budgets to meet increasing environmental demands. Simply ticking the environmental box with one hand, while not paying attention to the long-term productivity and satisfaction of building occupants is not financially sensible, nor is it appropriate for developing a feeling of personal, business or national well-being.

Environmental obligations either implied through various UK regulatory requirements e.g. UK Climate Act (2008)[4], UK Building Regulations (2015)[5] or through individual corporate & social responsibility (CSR) policies, have now become a major cost burden to most UK businesses. The cost of carbon for example is relative to FTE and building efficiency, CSR obligations are a relatively new on-cost requiring more FTE and investment to achieve compliance, Reacting to these obligations by creating sustainable low carbon buildings does not necessarily mean our buildings become healthier, improve our health & well–being or indeed make building occupants more productive. In fact it can be quite the opposite.

The need to develop more intelligent & sustainable buildings that offer an opportunity to extend our vision towards satisfying occupant expectations has never been more important. The design of more intelligent buildings and workplaces to combine and meet occupant and building performance criteria is becoming considered a major step forward in meeting a sustainable agenda and for managing life cycle costs (Clements-Croome (2007). Designing buildings focussed upon occupant needs and not simply Target Emission Ratios (TER within a BREEAM framework for example, will focus buildings toward Intelligent Building, design construction and operation, reducing the overall costs to any organisation.

The Hive building in Manchester is a perfect example of where new intelligent architecture, naturally ventilated mixed mode designs are moving the workplace forward. The buildings simplistic architecture for satisfying occupant needs within a naturally ventilated well insulated and low energy building is making the case for examining how we think about designing new modern buildings. Is this approach intelligent or is it simply common sense, do we need to embed such ideals into the fundamentals of how we view buildings, There is much to consider and the response to these suggestions is perhaps yes, but we must be conscious of business identity, workplace efficacy and the specifics of each and every project.

1.3 The Rationale for Occupant Defined Buildings

When considering the new concept of occupant defined buildings we should acknowledge that they are in some form intelligent serving the needs of the occupant business and environment. By meeting the needs of occupants and in achieving the criteria requirements set by the many stakeholders involved they become successful environments. If we therefore accept that such buildings are indeed intelligent, Clements-Croome (2007) supports they should also be sustainable, healthy, technologically advanced and meet the needs of their occupants & businesses. They should be flexible and adaptable to change. A DEGW/Teknibank research project in 1992 however, offered an alternative intelligent building definition, proposing an intelligent building is one that provides a responsive, effective, and supportive environment within which the organisation can achieve its business objectives.

Fig. 5 – Maslow Hierarchy of Needs (1943)

Both of these definitions share the common theme of supporting a sustainable business, yet there are many differing definitions available. From an occupant perspective, Maslow's psychological hierarchy of needs (Fig. 5) presented in 1943 (Maslow 1943) and Herzberg's two-factor theory (Herzberg et al 1959) (Fig. 6) have offered an occupants view of the workplace and to what is important to the individual. This occupant view is now shaping our

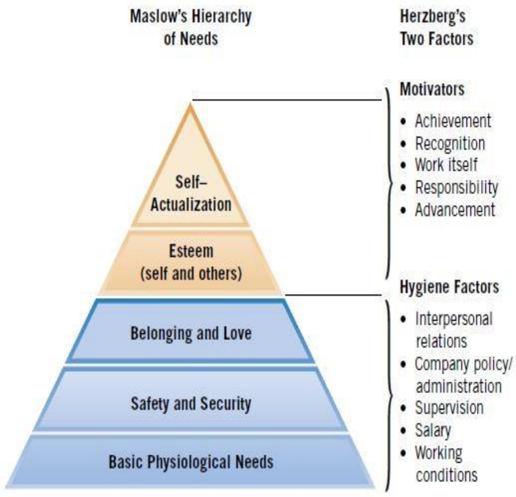


Fig. 6 – Maslow & Herzberg Human Factors (1959)

workplace concepts and is changing the way we think about buildings. Intelligent buildings are not simply green low energy/carbon performing buildings they are seen as communities that promote personal satisfaction, health, well-being, achievement and business success.

Herzberg's two-factor theory connects well with Maslow's human needs. Herzberg's "hygiene factors" however, possess a slightly more negative effect towards the individual, whereas his defined physical "motivational factors" possess a more positive relationship. Accepting the principles of Maslow and Herzberg now exist within the context of buildings, the workplace has an important role to play in satisfying occupant well-being and personal satisfaction. The need to consider these basic human aspects within the design and operation of buildings therefore begins to become a fundamental consideration, particularly if we are to create the ideal work environment for sustainable success and well-being. Merely designing, constructing and operating buildings to satisfy investment criteria will simply not satisfy our basic human needs, and may subsequently make occupants even less productive. We must therefore recognise that psychological and physiological responses to our immediate environment are important to deliver occupant satisfaction, health & well-being, but also accept the existence of more basic physical aspects need to be recognised.

The direct physiological impacts from the indoor environment are viewed across two distinct levels; firstly the direct impact to the human senses e.g. lighting glare, noise, CO_2, air quality or thermal discomfort; and secondly the corresponding psychological impact created by such physical stimuli.

1.4 The Economic Opportunities for Business

Building life cycle cost (LCC) reviews undertaken by Evans (1998) and Oseland & Willis (2000), sought to consider the financial relationships associated with design, construction and the operation of buildings. They concluded that a typical capital and operational cost distribution existed, subsequently proposing a typical LCC cost ratio of 1:5:200 - design & construction (x1); operation & running (x5) and business costs which are largely salaries (x200). When we incorporate time into this equation, we begin to see the importance that key design decisions may have over the building life cycle, and the possible financial impact by making the wrong investment decisions at

such an early stage (Fig. 7). The rational for occupant defined buildings is becoming evident.
With contractors attempting to maximise project margins post declared tender margins and endeavouring to meet unrealistic construction deadlines, the construction phase has dilemmas and dynamics of its own when attempting to adopt a occupant defined building approach. The building energy performance gap being consistently experienced (design v actual consumption) can be said to be a consequence of poor design and construction, but it is also a consequence of not placing the occupant as a key performance denominator or as a key consumer of building resources.

Accepting conflicts will inevitably exist at the front end of the design & construction process, we need to be pragmatic when attempting to adopt or present a whole life cycle value principle (Fig. 7). The dilemma faced when proposing the long-term benefits of adopting occupant defined buildings or whole life cycle value (WLCV) principles which support occupant defined buildings, is they need to be quantifiable at the initial investment stage otherwise they have no credibility. The use of financial investment calculations detailing modified internal rate of return (MIRR), net present value (NPV) and even simple payback (PB) periods are however tools that support this argument, but they are pure financial reviews with no awareness for their affects upon occupants or building performance.

***MIRR** – a financial measure of an investments attractiveness and used in capital budgeting to rank alternative proposals of equal size.*

***NPV** – the sum of future values over a period time calculated to provide a current day value to enable different investment decisions to be made*.

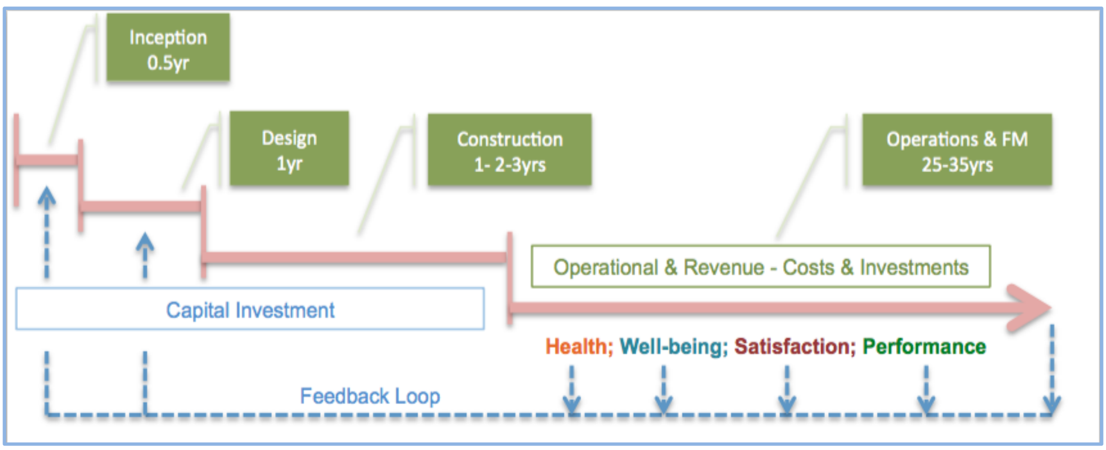


Fig. 7 – The Design, Construction & Operational Investment Timeline

What we believe to be one of the key cost drivers for businesses i.e. energy costs, actually only represents 1% of total business operating costs according to a recent (2014) World Green Building Council (WGBC) report [6]. Driven by occupation rates and business requirements, buildings and workplaces exhibit a re-curing and embedded energy profile not previously considered important. Borne as a consequence of design, but more interestingly in how buildings are operated, it is this previously unconsidered occupant and business relationship that may be a significant contributory factor towards the energy performance gap. It is therefore essential, if we are to create the most effective workplace environments, that we recognise a balanced energy equation needs to exist between design and operation. If we accept the existence and requirements of a balanced energy equation, then it is vital we maximise the effectiveness of workplace IEQ factors in order to enhance occupant satisfaction and performance while using minimal energy resources. We also need to keep designs simple and effective using intelligent thinking, technology and operational practices to put people as key driving factors, and not to focus entirely upon energy or construction cost.

We have not yet seen the zero carbon commercial office building, however technology is advancing rapidly to provide self-supporting buildings inclusive of embedded resource generation. Offices themselves however, do not consume energy, nor do they need to exist, it is the business operation and the staff that drive such consumption. Therefore, designing our buildings focussed upon occupant patterns, specific user needs and business requirements should ultimately drive lower energy consumption and improve occupant satisfaction, health & well-being.

Looking specifically at operational costs (Fig. 8) the timelines involved and LCC cost ratios, they tend to suggest our focus should clearly shift to securing occupant and business performance, as this is where the highest cost to businesses exists. Organisations which recognise this fact and its relationship, will potentially be the most successful long-term. We can observe in Fig.8,

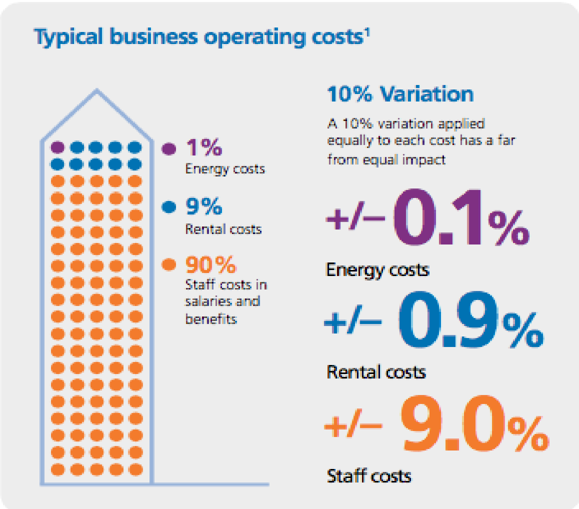


Fig. 8 - Typical Business Operating Costs
Source World Green Building Council – 2014[6]

three distinct cost areas; 1) ***energy costs*** influenced by design, 2) ***rental & service costs*** incurred by necessity, building design and its location, and 3) ***staffing costs*** influenced by occupant performance, productivity, health & well-being.

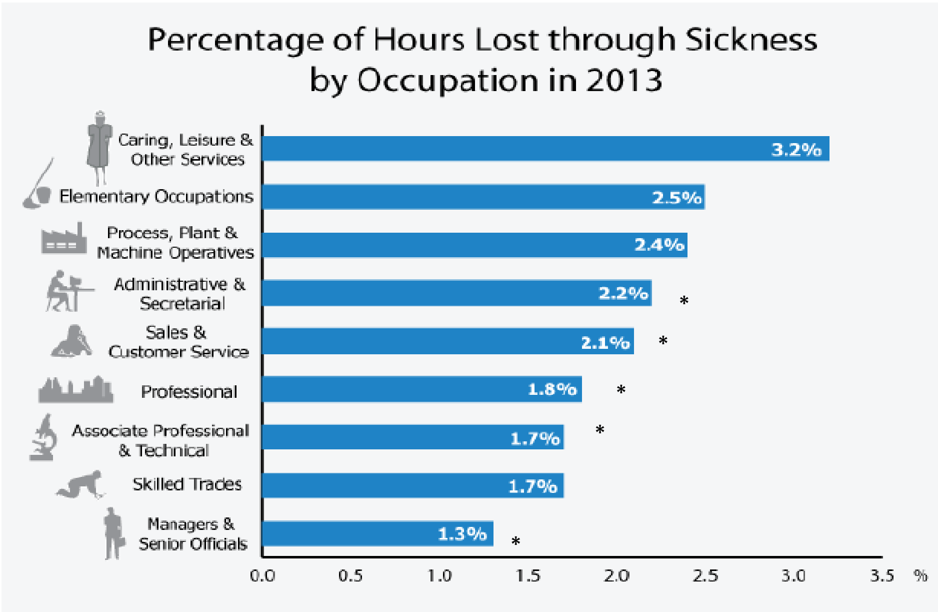
Property ***rental costs*** however, are premised upon three main and definable characteristics; the size of the building, the quality of the building, and its location. As we have seen within Fig. 4, there is some consideration that location is currently a key cost driver, therefore given the scale of these cost, this may be an area which can be exploited to promote WLCV principles. With rental costs varying significantly in response to external economic and market factors, the one common denominator of staff and function remain the key cost performance ($£/m^2/_{FTE}/_{time}$) factor for many organisations.

Business ***staff & salary costs*** are by far the largest single expense for any organisation and include specific elements such as salaries, bonus, tax, insurances etc., but they also include other non-productive elements such as absenteeism and lost production. The latest UK Labour Force Survey report issued in 2014[7] and prepared by the Offices for National Statistics (Fig. 9) indicates 131million days were lost during 2013 equivalent to 4.4-days for every UK worker. Over the past 20-yrs however, the number of working days lost within the UK has seen a +ve 26% reduction, but this is thought to be more as a result of increased health & safety legislation rather than a change in worker or business practice.

Fig. 9 – UK Working Days Lost 1993 – 2013 - *Source UK Office National Statistics*

Analysisng the various industry sectors contained within the report (Fig. 10), we begin to understand the various sickness rates associated with buildings (*). The data summariesed within Fig. 10 unfortunatley however, details the total hours lost across all UK industry sectors, with office type environments absorbed across a number of other sectors. But when we consider the total UK hours lost through general sickness and across all industry types, this equates to 18.8% of all absenteeism recorded.

However, if we take a discrete office building perspective this figure reduces to 9.1% but is still almost ½ the total amount of hours lost across all industry sectors.



Source: Labour Force Survey - Office for National Statistics

Fig. 10 – UK % of hours lost due to sickness – 2013 (only) - Source: UK Office of National Statistics
Note: we spend approximately 22.8% to 41.6% of our conscious (waken) time within a work environment.

Absenteeism is a major cost burden to most businesses and to the economy, therefore any improvement in the health, well-being and level of personal satisfaction of building occupants can only improve the long-term absence outlook.

According to a CBI report (***Getting Better – Workplace Health as a Business Issue***) released in 2013[8], lost productivity cost the UK economy circa £14bn in 2012, with a direct cost to UK business estimated at circa £1.14bn/year. In this one year alone (2012), lost productivity was equal to the total annual rental value of the whole UK property office sector (£13.9bn). Similarly a 2008 report presented by Professor Dame Carol Black titled “Working for a healthier tomorrow – Review of the health of Britain's working age population"[9] summarised the total cost of absenteeism and its impact to the UK economy at a staggering £100bn/year adding it is simply not sustainable. In comparison, the UK's defence and National Health Service (NHS) budgets are £45bn and £135bn respectively.

1.5 Workplace & The Occupant – Health & Well-being

Analysing how we design and operate our buildings, we already know that workplaces and occupant productivity are inextricably linked (Leaman & Bordass 2001), however we rarely monitor or manage this relationship to assess actual levels of performance.

When endeavouring to define a persons general state of existence, the words health & well-being have by their association become intrinsically synonymous in helping to define intelligent buildings. The term health & well-being is now used as a barometer for assessing a general feeling of satisfaction, happiness and existence, however, it has become a ubiquitous term without pre-defined boundaries. We have grown a natural mentality in understanding what is bad for us, but we are yet to realise what is actually good for us and to encapsulate these factors into a framework or standard. In trying to understand what is good for us, it is perhaps important that we understand and consider the term health & well-being, and to form a definition specific to workplace environments rather than a ubiquitous term.

Well: *(adverb)* "*in a good or satisfactory way"*
Well*: (adjective)* "*in good health and free or recovered from illness"*
Being: *(noun)* "*the quality or state of having conscious existence"*
Health*: (noun) "the general condition of being sound in body, mind, or spirit, and free from physical disease or pain"*

Source: Oxford Concise English Dictionary

Buildings and workplaces even of different types are known to directly influence occupant health, however, when we attempt to investigate the term "well-being, we realise although a simple statement the term is quite complex. One of the main difficulties in defining well-being, is that it is universally referenced across many applications and indeed environments, being applied subjectively and objectively in many instances. Therefore, to assess a specific view of well-being, it is important to define it within its own individual context and to empirically understand the various tangible factors.

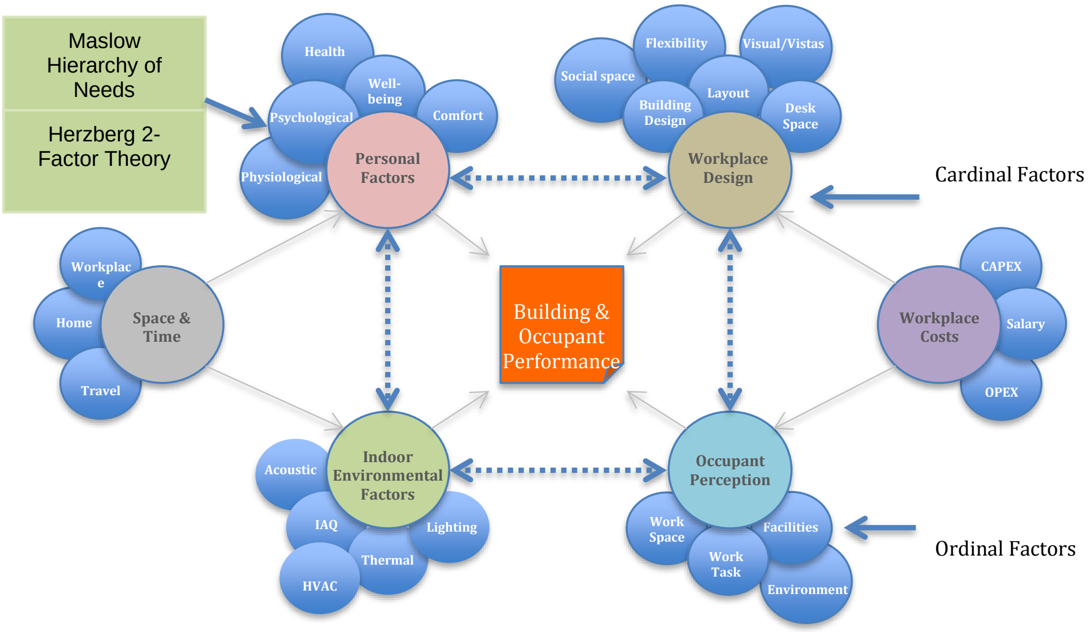


Fig. 11 The Building & Occupant Performance System – Developed from Clements-Croome 2016

Seen by many, as a subjective perceived state of existence, health & well-being forms two of a number of ordinal factors which interact with cardinal factors to drive building and occupant performance (Fig. 11). Assembling a specific definition based upon a physiological approach our unique definition for health & well-being extends to designing & operating "***intelligent workspaces which not only keep the building occupant free from physical disease or pain, but support the individual effectively without stress, offering a quality environment responsive to individual needs and desires".***

Demonstrating the many aspects (Fig. 11) that drive and support building and occupant performance, the complex nature of the interactions between various IEQ factors needs to be standardised. Analysing these interactions, we propose that building and occupant performance are indeed inter-linked, and by using the term performance, we may begin to analyse the efficacy of our workplaces to a common set of key performance indicators (KPI's).

We therefore propose to define "occupant performance" "***as the ability to perform within a measured and controlled environment consistently, accurately and productively over any reasonable accepted period, and to remain engaged with***

the task being performed within a defined set of IEQ workplace & physiological factors”.

What we are creating and discovering is the very DNA of a building, how it learns, operates and how it functions relative to the people who use it.

1.6 Research Aim & Objectives

The primary aim of this research (Fig. 12) to assess the impact of indoor environmental quality factors to create an enhanced post occupancy evaluation model (ePOE) linking IEQ factors, occupant physiological responses and subjective perceptions within the office workplace. The research is being applied to assess the impact of indoor environmental quality factors upon occupant performance within a typical office environment, and compares IEQ relationships across two naturally ventilated buildings. The research further assesses the relationship between IEQ factors and building users, and to what impact these factors may have upon occupant physiological performance.

The research questions being answer are noted below:

Q1 - Which IEQ factors have an impact upon occupant physiological performance?

Q2 - How to measure and interpret the affects IEQ factors place upon the occupant?

Q3 - How to prioritise IEQ factors to promote health, well-being & performance?

Q4 - How to adopt real time IEQ & physiological data to inform building occupants?

In support of the above research questions, three key objectives are defined to satisfy the research aim

The three key objectives are achieved by adopting nine (9) primary support tasks. In deriving and summarizing our research (Fig.12), the research is structured through each branch of an aim, objective and task tree diagram.

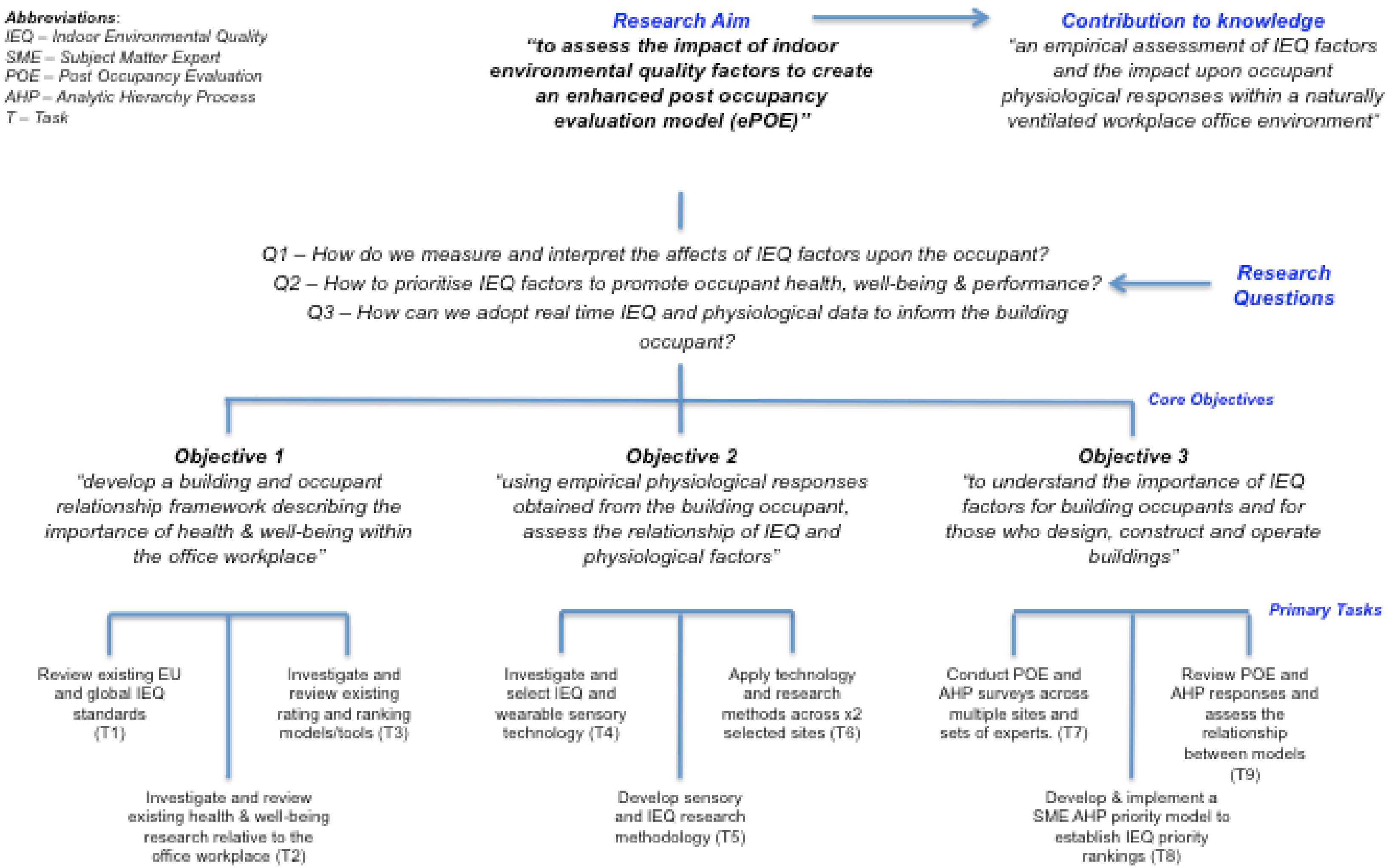


Fig. 12 – Research Aims, Tasks and Task Tree.

1.7 Contribution to Knowledge & the Property Industry

Our key contribution to knowledge seeks to deliver a defined and integrated Building Agent Model (iBAM) to allow design teams to predict best value design options thus creating high performing workplaces with satisfied building occupants. This contribution will further seek to inform the development of a potential new British/EU standard to enable architects and building services engineers to focus upon the primary aspects of health & well-being and to reduce the energy performance gap.

This research project will propose four specific benefits from which the industry may benefit, and these are referenced below and discussed further within Chapters 8 & 9.

1. Reduced environmental impact by designing for occupant specific needs.
2. Support the production of a new standard specific to IEQ factors.
3. Allow investment decisions to be based upon WLCV principles at design stage.
4. Improved economic performance through a healthier, happier, more satisfied and productive workforce.

Although these key benefits can be said to be attributable to our research, we must recognise they are independent benefits that will require further resource in order for them to be delivered. Also, there will be a need to review how to promulgate these benefits and how they can be verified and validated.

1.8 Research Summary

Our research hypothesis proposes that by using subjective and empirically measured IEQ values, that a criteria-rating system can be developed to support the promulgation of health & well-being as a vital investment criteria for intelligent workplaces. In support of our hypothesis a research methodology has been structured around six distinct elements described further within Chapter 3 but summarised below:

1. A literature review of existing global IEQ and health & well-being standards including assessing existing IEQ research methodology has been undertaken to develop the research methodology and is described within Chapters 2 & 3.
2. A specific Post Occupancy Evaluation survey have been developed and delivered using the Bristol On-line Survey (BOS) e-survey tool.

3. Semi-structured interviews with property industry professionals have been undertaken across architects, building services engineers, owner-occupiers and research associations.
4. Indoor environmental monitoring of the workplace using the parameters scheduled within ASHRAE Guidance Note 55[7] have been applied and are correlated with the sensory measurements obtained from each of the volunteers. Deployment of field equipment at each selected site incorporating (x4) environmental monitoring poles and background monitoring equipment.
5. Occupant sensory measurements have been obtained using sensory armbands and vest technology.
6. Based upon a defined set of semi structured interview questions expert responses are assessed within an Analytic Hierarchy Process (AHP) providing a priority ranking for IEQ, Workplace factors (WPF) and occupant responses.
7. Descriptive statistical analysis is used to summarise and describe the various data sets obtained, with multiple linear regression techniques used to assess the relationship between different variables.

Various elements have required either ethical or health & safety committee approval from the University of Reading and these submissions are detailed with Appendix A & B.

A review of proprietary AHP software was completed to select the most appropriate ranking tool, this is detailed further within Chapter 3 and is accompanied with explanatory mathematical modeling and a AHP matrix diagram.

The structure of the thesis, its outline and an explanatory diagram are described further within Section 1.10.

1.9 Thesis Outline and Plan

The thesis is framed in three key parts and is covered across eight (8) chapters and appendices (Fig. 13).

- ✓ ***Chapter 1* – Introduction:** Provides background to the research and introduces commercial property industry fundamentals, rationale for the research and key industry issues that are driving the need to review current IEQ guidance and knowledge. Existing research focuses upon ranking and rating the impacts of IEQ factors, but has not fully transferred this knowledge into a useable predictive model or tool that design teams can practically adopt.

- ✓ ***Chapter 2* – Literature Review:** provides a review of known IEQ and workplace factors assessing these factors against existing building occupant physiological research. The chapter describes the physical environment of thermal comfort, acoustics, Lighting, industry building metrics, as well existing health & well-being research. The literature review also provides a foundation for developing the field research methodology, monitoring and measurement techniques, and adoption of adapted POE and AHP techniques. In addition we review existing global standards associated with health & well-being and indicate were standards are insufficient and/or can be developed.

- ✓ ***Chapter 3* –** Research Methodology: Describes the research methodology, tools & techniques selected from Chapter 2 and describes each specific aspect and how they link to support the key objectives and research questions. Environmental IEQ data collection devices, characteristics and parameters are also described in detail. This chapter also covers the development of an adapted POE survey, interview techniques and AHP process, and describes the statistical methods adopted to describe and present the data across Chapters 4, 5 & 6.

- ✓ ***Chapter 4* – Building Performance Surveys:** Translates POE and AHP survey responses graphically and statistically, segmenting responses into groups prior to correlating with the environmental and physical occupant data. The AHP analysis provides a ranking and rating view from the AHP subject matter experts and leads to propose a criteria model discussed within Chapter 7

- ✓ ***Chapter 5* – Occupant Physiological Measurements:** Provides a detailed view of the sensory physiological data measured across the two sites and the four volunteers engaged at each site over the 12-month research period. Individual measurements are compared to expected known standard medical values and are assessed against measured IEQ results to validate statistical correlation. The two sites are reviewed and assessed against IEQ values.

- ✓ ***Chapter 6* – IEQ Monitoring Data:** Reviews the environmental measurements obtained across the two sites, correlates between each site and assesses issues noted during the research periods. The IEQ results are correlated against the occupant sensory results (Chapter 5) to assess the existence of any direct relationships, and to enable the results to be compared against POE and AHP results described within Chapter 4. A statistical assessment is presented within the chapter and is further summarised within Chapter 7.

- ✓ ***Chapter 7*** **– Research Discussion:** Discusses the research findings, describes anomalies and proposes potential socio-economic benefits. This chapter also summarises Chapters 4, 5 & 6 and highlights areas were positive and negative impacts have been discovered. The correlation between the sites and individuals are noted and explained and the research questions defined within Fig. 12 are reviewed and validated across the previous chapters.

- ✓ ***Chapter 8*** **– Conclusions & Further Work:** Provides a conclusive review of the holistic research taking account of practical and analytical results. The success of the research in meeting the questions and objectives described within Chapter 1 is also reviewed, and further recommendations are proposed to enhance the research based upon the conclusions reached. This chapter also describes the originality of the work and its contribution to knowledge.

- ✓ ***Appendices*** **–** These contain adapted POE survey templates, statistical outputs, AHP model data, transcribed SME interviews and ethical forms.

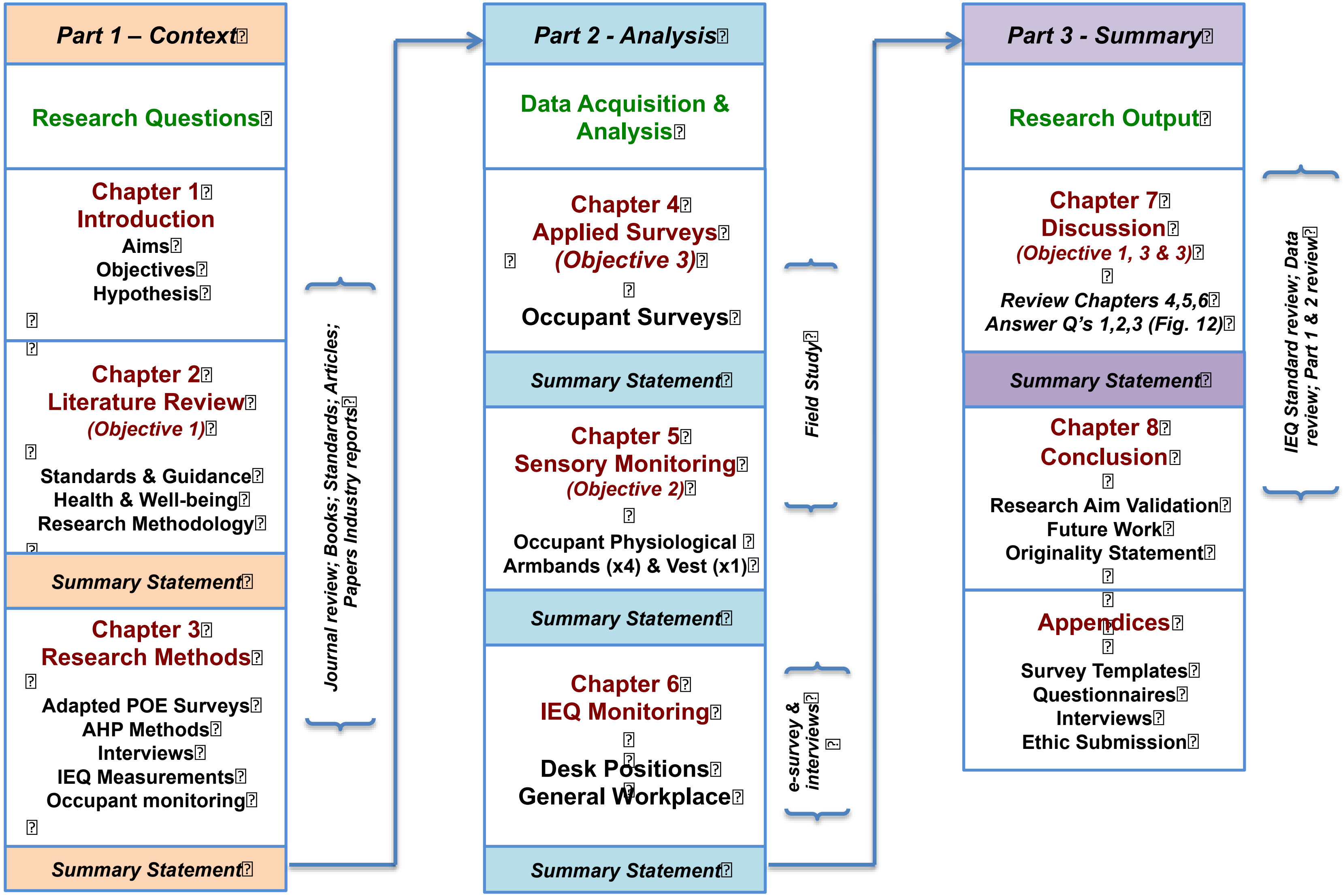


Fig. 13 – Thesis Structure & Outline

Chapter 2 - Literature Review

Introduction

This chapter comprises of three parts and assesses the relevant literature associated with IEQ environments and other similar research studies to deliver an ePOE model. The first part of this chapter reviews existing IEQ research, framing the subject and its importance within the relatively wide subject area of occupant satisfaction, productivity and well-being. The second part assesses the relevant global standards, coverage and describes how they are applied. The third part reviews building performance techniques and describes the principal use of the various POE models available. A chapter review is provided to summarise the literature review, which then facilitates a transition into the following Chapter three – Research Methodology.

Part 1 – The Importance of Existing IEQ Research

Poor indoor environmental quality (IEQ) has over many studies been related to increases in sick building syndrome symptoms, respiratory illnesses, sick leave, and losses in occupant productivity. The actual cost impact as a consequence of poor IEQ differs form building to building according to Ive (2006), however, the cost impact of poor IEQ factors and their subsequent affect upon building occupants can be higher than the actual energy costs associated with the buildings air-conditioning and ventilation systems. The many measures taken to improve IEQ could offset some of these cost impacts, and could be highly cost-effective when accounting for the monetary savings from improved occupant health and/or productivity (Seppanen & Fisk 2006).

2.1.1 Productivity, People, Buildings & Environment

In ways that are both objective (physical) and subjective (psychological), workplaces and the wider built environment affect our general state well-being. Buildings affect people in different ways, they can help us to work more efficiently & effectively, but they also present a range of stimuli to positively or negatively impact occupant performance (Clements-Croome 2014). Poor working environments are known to contribute specifically to sickness and absenteeism (Rolefson 2001; Prellar et al 1990; Bergs 2002), and which can significantly affect the productivity and performance of building occupants (Fisk 2000). High-quality workplace design is therefore considered to be a long-term investment for making occupants healthier, happier and for encouraging their perceived feeling of well-being.

Based upon the best available evidence at the time, it was proposed by Sepannen & Fisk (2006), that a quantitative relationships exists between; 1) ventilation rate and short term sick leave; 2) temperature and occupant performance; and 3) perceived air quality and occupant performance. Four existing studies set within a call-centre environment were studied to assess ventilation rates and performance (Heschong group 2003, Federspiel et al. 2004, Tham 2004, Wargocki et al. 2004). The statistically adjusted data within these studies, suggested a relationship existed with improved ventilation rates, further concluding that an optimum performance increase was achieved at approximately 14 and 16L/s-person based upon statistically significant results of 95% & 90% respectively. However, if we consider the cost benefit and the existence of a diminishing rate of return to achieve such an increase in performance, then the study does not offer a viable or standard design solution. The cost to achieve these ventilation rates on hi-density workplaces for example will be prohibitive, and therefore a range of ventilation rates will be required and a new model to assess the level of performance achieved for each different workplace.

Significant studies in Denmark (Wargocki 1999) reported that a relationship did exist between perceived air quality (PAQ) and the relatively simple task of copying typing. Further study reviews by Seppannen & Fisk (2006) suggested that performance might actually not be as a direct result of PAQ, but rather other factors as a consequence of poor air quality or ventilation rates. Subsequent further work by Wargocki (2000) and Bako-Biro (2004) and based upon data obtained from the European Audit project (Bluyssen et al 1996), determined that perceived air quality varied between 2-9 "decipols (dp)" corresponding to a 25-60% level of dissatisfied responses. (*1 decipol (dp) is defined as the PAQ unit (Fanger 1988) within a space with one sensory load of one "olf" (one standard person) and ventilated by 10 L/s).* Wargocki (2000) and Bako-Biro (2004) calculated this *decipol* difference to equate to a 3.8% (office task) and 2.8% (typing) improvement in performance respectively. The problem with the modern workplace however, is that there are many different tasks and typing is not a definable performance output anymore.

Within many commercial buildings, thermal conditions are not well controlled. They suffer from high and dynamic internal and external gains, large thermal zones and improper control systems (Sappenen & Fisk 2006). From 150 assessments of thermal performance from 26 separate studies, Sappenen & Fisk discovered statistically that occupant performance values increase between the values of 20-23°C, yet decrease with temperatures >23-24°C. Concluding that a quantitative relationship between IEQ factors, health and productivity differs between buildings, it is important to see each workplace as a unique interactive space. For example, a high ventilation rate in one building with very poor IAQ is known to positively affect performance due in part to contaminant dilution, however, in a building with low pollutants their will potentially be no change in performance due to little discernible impact. It is also recognised that responses to IEQ improvements will have different affects for each individual within their unique environments, and also as a consequence of the type of work being conducted. It is also important to note, that IEQ improvements may combine, and therefore it becomes difficult to assess which improvement contributed to any increase in performance.

2.1.2 – IEQ Factors and Productivity

We have previously stated that productivity is difficult to define within the office type workplace, however, within a Call-Centre type environment, it is feasible to consider productivity by associating IEQ factors to call response rates. A 2004 field study (Tanabe et al 2009) concluded that call response rates differed seasonally and were affected by rises in temperature of even 1°C. Several other call-centre studies (Wargocki et al 2003; Federspiel 2004) also concluded similar results, particularly concerning indoor air quality and ventilation rates.

Based upon REHVA Guide No.6, research in the Netherlands by Leyton and Kurvers (2010), sought to investigate the assumptions that quantitative relationships did exist across specific IEQ factors, productivity and absenteeism. The study concluded the following relationship did in fact exist – (Table-3)

IEQ Factor	Occupant Relationship
Temperature	Productivity
Perceived IAQ	
Ventilation	Productivity & Absenteeism

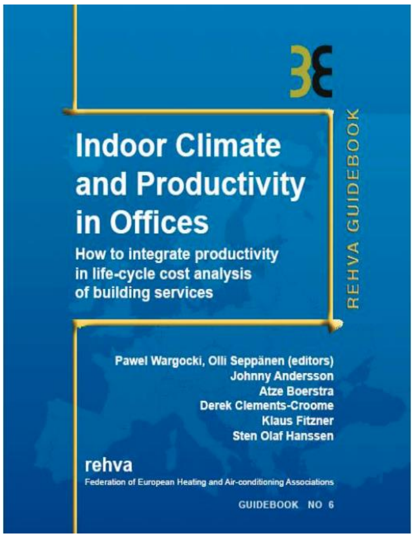


Table 3 - REHVA Guide No.6 – IEQ Occupant Relationship Model – Leyton & Kurvers (2010)

Wai Tham et al (2015) completed a study of LEED rated buildings to assess IEQ occupant perceptions and their associated Sick Building Syndrome (SBS) symptoms. The study concluded that “Green” (LEED) certified buildings did not have better IEQ results or even lower sickness levels than non-certified buildings, however, there were significant differences in CO_2 profiles, bacterial coli forming units (CFU/m^3) i.e. cleanliness, and air quality particulate levels. The occupant perception of IEQ factors did in fact differ between the two selected offices, but this could be assessed as being as a consequence the survey questionnaire design and also the differing building environments.

2.1.3 – The Key Aspect of Thermal Quality

Due to the nature of field-work within a live office environment, most thermal performance assessments have been conducted within a laboratory environment. Weilin et al (2013) developed a test chamber memory-typing test with the specific purpose of clarifying the influence of temperature (objective factor) and motivation (subjective factor) upon human performance. Five steady state temperatures were used; 22^oC; 24^oC; 26^oC; 29^oC & 32^oC and each experiment lasted 150mins. Physical measurements of air temperature, humidity and air velocity were obtained for the IEQ factors within the test chamber. Three occupant survey formats were used; 1) a subjective questionnaire using the ASHRAE/ISO 7-point thermal sensation scale; 2) a thermal comfort vote survey (TCV’s) using a 4-point numerical scale (0 = Comfortable; 1 = slightly uncomfortable; 2 = uncomfortable; 3 = very uncomfortable) and 3) a motivational questionnaire using a 7-point Likert scale survey template (0 = extremely low; 1 = very low; 2 = slightly low; 3 = Neutral; 4 = slightly high; 5 = very high; 6 = extremely high). The results from these experiments proposed that air temperature and motivation affected human performance, however, it was considered that motivation was a better indicator for human performance rather than temperature.

2.1.4 – IEQ Factors and Integrated Building Control

The importance of thermal comfort is reflected by Liu et al (2014) as a means of interacting with IEQ factors and by adapting to the conditions through building interaction. Using similar survey and research techniques to Weilin et al (2013), Liu supports the theory of Nicol, Humfreys and Roaf (2012) that the adaptive approach to comfort is based upon a simple control principle; if a change occurs so as to produce discomfort, then people will react in different ways to restore their preferred comfort level. It is proposed therefore that adaptation may be used to influence building and human performance to drive energy efficiency, however, Liu et al (2014) adds, that by using intelligent feedback systems the possibility of integrating the building with occupant comfort factors and their subsequent behaviours, this approach will actually drive energy efficiency and occupant comfort. Who dictates and controls the IEQ environment is a key principle to consider, the ability to control your environment has been proved to increase productivity and levels of personal satisfaction (Bordass and Leaman 2007), but many control issues exist to prevent the adoption of this principle.

The SMODIC model (Fig. 14) - **sm**art sensors, **o**ptimum **d**ecision and **i**ntelligent **c**ontrol derived by Yao and Zheng (2010) supports the work by Liu. Taking workplace IEQ data, occupant responses and applying a multi criteria decision-making process (MCDM), we begin to see how we could connect the building to the occupant. This objective model, emphasises the point that occupant adaptation within the workplace, requires interaction with workplace IEQ factors, and if we are to minimise the conflict between occupant comfort and energy efficiency, then we need to measure and interpret building and occupant data.

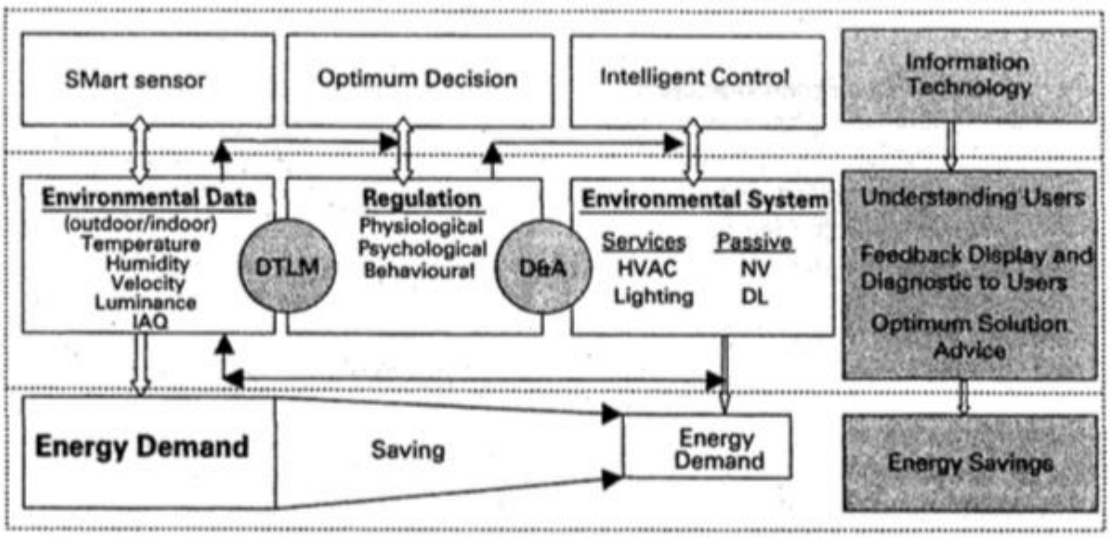


Fig 14 - SMODIC Building & Occupant Control Model (Yao, Zheng – 2010)

Analysing the factors that affect occupants within intelligent pervasive spaces - the collection of factors and data across ubiquitous spaces, Moran and Nakata (2011) propose that a model can exist to predict occupant behaviour. Within such a model, discrete monitoring devices are secreted upon the occupant to gather behavioural data, with the model subsequently interpreting the data to predict overall building performance. It could also provide building and/or occupant feedback loops.

2.1.5 – Integrating People within the Workplace

Monitoring people smartly to reduce energy consumption has in the past been the primary rationale for attempting to connect occupants, their behaviours and their expectations to the building. Using the premise that if occupants are informed about their energy footprint they can then adjust their behaviour (Darby 2006), then this principle could be adopted to influence the performance of IEQ factors by using occupant information sent back to the building systems (Spataru and Gauthier 2014) and vice versa. To assess the personal loads deposited within the workplace, Spataru and Gauthier researched this feedback approach and the available sensors which could be deployed to obtain building occupancy patterns. They subsequently recognised that both physiological and environmental sensors were also necessary in order to obtain the relevant IEQ and occupant empirical data. Andersen et al (2008), suggests that by delegating indoor environmental controls to the occupant, this increases the difficulty of predicting building performance. However, if as Agha-Hossien (2015) suggests a link does exist between occupant behaviour and building energy consumption, it is therefore important to understand these relationships discretely. Again, although energy focused, this building and occupant relationship augments well for aligning the performance of IEQ factors with occupant physiological responses.

2.1.6 – Intelligent Building Principles for Better Buildings

The emergence of Intelligent Building (IB) principles is now at last getting to grips with what should be a discrete relationship between the building and its occupant. The main features of IB's, are identified by Kell (2005) across six key building attributes:

1. IEQ factors are automated in some respect.
2. Posses integrated, informative and responsive adaptive systems
3. Rely upon passive intelligence to replace unnecessary active systems
4. Integrated occupant intelligence enabling direct occupant connectivity
5. Organisational intelligence integrates the building capability and its potential
6. Intelligent space management exists to adapt to changing business needs

Kell (2005) goes on to emphasise that a common factor associated with IB's is that they focus more towards the use of information to improve performance and to increase value to any organisation. Sustainability issues as an example are now driving a fundamental re-thinking of the relationships between human behaviour, needs, workplace processes, and building systems and how they might evolve (Cole and Brown 2011). Exploring the possible links between IB's and human integrated intelligence, Hinanen (2004) proposed that several possible artificial components exist.

1. Integrated functional connectivity offering the occupant personal control and/or information exchange.
2. Building self recognition a state of conscious state of awareness
3. Adjustable technology and building services
4. Embedded sensory logic to monitor the building occupant - kinaesthetics - *the study of body motion, and of the perception (both conscious and unconscious) of one's own body motions*

Cole and Brown (2011) raise the question of competing demands within IB's. The provision of comfort, heath and well-being while achieving operational efficiencies, is a continuing dilemma. They propose that Kell's (2005) "occupant intelligence" concept is possibly where a solution may exist, thus allowing users to integrate more directly with their workplaces so that more adaptive levels of comfort and productivity may be delivered.

2.1.7 – The Awareness of Occupant Well-being

Workplaces also reflect the culture of companies and are places that are not only functional and convenient, but they are environments and communities offering a wholesome experience for both the body and spirit (Clements-Croome (2007). The UK Green Building Council within their report, *Health, wellbeing and productivity in offices: The next chapter for green building (2014*) supports this view of Clements-Croome. The report suggests a range of intelligent building design features from air quality and day-lighting, to views of nature and interior layout can influence the health, satisfaction and performance of office workers. Making the case for intelligent building adoption to support increased productivity, an intelligent work environment should also be able to sense the interaction between occupants using the space, subsequently processing this data to meet user expectations (Reijula et al 2011).

According to Chiang and Lai (2002), the indoor environment is complex and is constituted of many inter-related factors, and in which building occupants reflect their environment through their physiological and mental sensations – sight, hearing, smell, taste, touch and their psychological well-being. This is also a view shared by Clements-Croome (2007).

2.1.8 – The Workplace as an Environment

Workplace environments have been researched from many different perspectives, however, the single most common agenda has tended to focus discretely upon occupant productivity. Previous research has defined the office as a single physical environment (Haynes 2011) but that it comprises of two main areas; ***office comfort*** (Oseland 1999, Leaman & Bordass 2000) and ***office layout*** (Becker and Steele 1995). Although a range of metrics exists to create a measure for these two areas, they are seen to be isolated from the socially and behavioural created environment that naturally exists as a function of the organisation and business demands. (Fig.15)

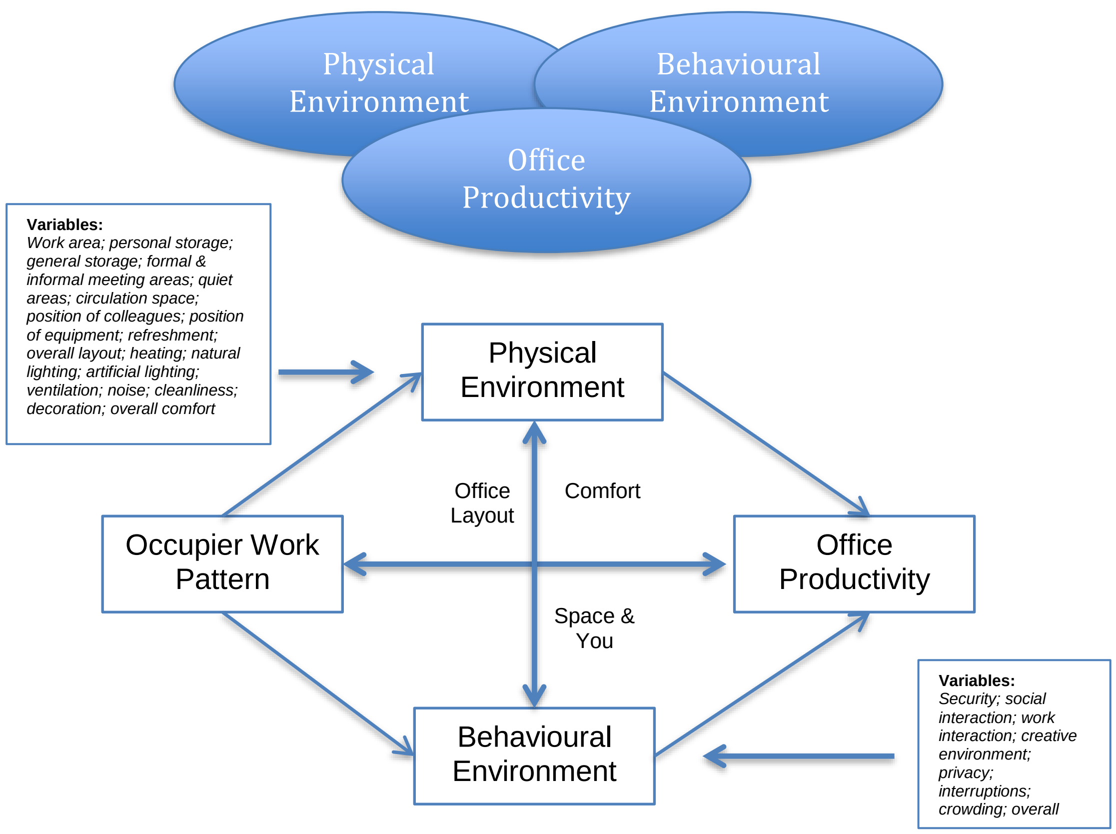


Fig. 15 - Theoretical Framework of Office Productivity – Adapted from Haynes (2009)

In the context of defining office productivity, it remains difficult to consistently or empirically measure productivity, either as an individual or as a business. The use of cross sectional and longitudinal evaluation surveys, has long been the typical method for obtaining occupant performance and productivity feedback, however they are difficult to maintain long-term and are time dependant. The Building Use Study (BUS), Leesman Index, Building Performance Evaluation (BPE) survey, BREEAM, Well Building Standard and the CBE Berkeley IEQ survey are just a selection of available evaluation survey tools which provide building occupancy evaluation output.

2.1.9 – Defining Productivity in the Workplace

The difficulty in obtaining an empirical value for occupant productivity, which is not purely a subjective response, has been a continual issue for building owners & operators. The CIBSE Technical Memoranda TM:24 has brought a clearer definition and process to defining productivity, however, it relies upon occupant subjective responses and assumed level of consistency.

Any collected (POE) data is relative to a point in time as it only provides the occupants subjective response to a given set of current circumstances. It is generally only applied for limited periods so can only provide periodic performance feedback subsequently taking longer to establish any particular trends. It is also very difficult to standardise empirical feedback as many different workplace environments and interactions exist. It therefore becomes evident that an individualised solution needs to be developed that can connect the occupants subjective and objective responses.

Within typical office environments, there is generally no tangible work-task output so it is difficult to establish a workplace environment productivity measurement or metric. Ilgen and Schneider (1991) however, suggested that three categories of performance measurement may exist, the *physiological*, the *objective* and the *subjective*.

Using a physiological approach offers the opportunity to measure the occupant physiological response to the environment and to subsequently associate these responses with measured workplace IEQ factors. McCartney and Humphreys (2002) proposed a method for analysing speech patterns for signs of fatigue as an example, while Nishiara (2002) sought to monitor cerebral blood oxygen levels. Both of these concepts possess significant application issues within real workplaces e.g. the ability to wear the sensors comfortably and the ability to measure individual speech in a crowded room is unrealistic, however, they persue the objective empirical principle. Wyon (1996) proposed and describes six possible productivity metrics (Table 4).

Possible Productivity Measures		
Metric	**Type of Measure**	**Comments**
Simulated Work	Performance of a realistic but artificial task	Periodically applied and interrupts work task and is unrepresentative
Diagnostic Test	Test procedure unlike any real task	
Embedded Tasks	Derived for an existing task	Does not represent the holistic level of individual performance
Existing Measures	Existing task measure – data processing; typing speed etc	May not cover all staff
Absenteeism	Review of sick leave records	Not all workplace related
Self Estimates	Perceived levels of efficiency and/or effectiveness	Periodic subjective response

Table 4 - Productivity Metrics (Wyon 1996)

2.1.10 – A Self-assessed Productivity Model

Following on from Wyon's *"self-estimation"* metric *(Table 5)*, Li and Clements-Croome (1998) developed a self-assessed productivity metric relative to various job factors. The self-assessed nature of this metric introduces a subjective occupant element, therefore additional inputs are required if the final results are to become more objective and empirical. Using an Analytic Hierarchy Process (AHP) questionnaire approach, Li (1998) discovered through his field research, that a number of principle factors affected self-assessed productivity and these were defined as; an overall unsatisfactory environment, an over crowded workspace and actual job dis-satisfaction were the key findings. The model itself is a very useful indicator towards assessing individual responses within large organisations.

Productivity exists as four cardinal factors: Social; Personal; Organisational and Environmental according to Clements-Croome (2007) and which is supported by Baldry (1999) who proposes that *"the work experience of every worker in every office is intimately affected by the qualities and organisation of the physical space".* The way it is laid out, the proximity to colleagues and mangers, the levels of acoustic and personal privacy and the quality of IEQ factors will often affect worker health and well-being according to Baldry.

2.1.11 – The Importance of IEQ Factors

The workplace provides the space for us to work, however it also provides many distractions consequently increasing the levels of stress and general energy expenditure (Dolan 2014). A person's *ultradian rhythm* i.e. their cyclical periods of concentration, and the concept of workplace *flow* (Demarco & Lister (1987) are important factors to consider when analysing productivity. Quality and productive work requires good levels of concentrations, and therefore it is important to understand how human systems deal with such periods of workflow. Various stressors can arise from the physical environment (Clements-Croome 2016) and these can exist across IEQ factors, a person's personal life and actual work tasks.

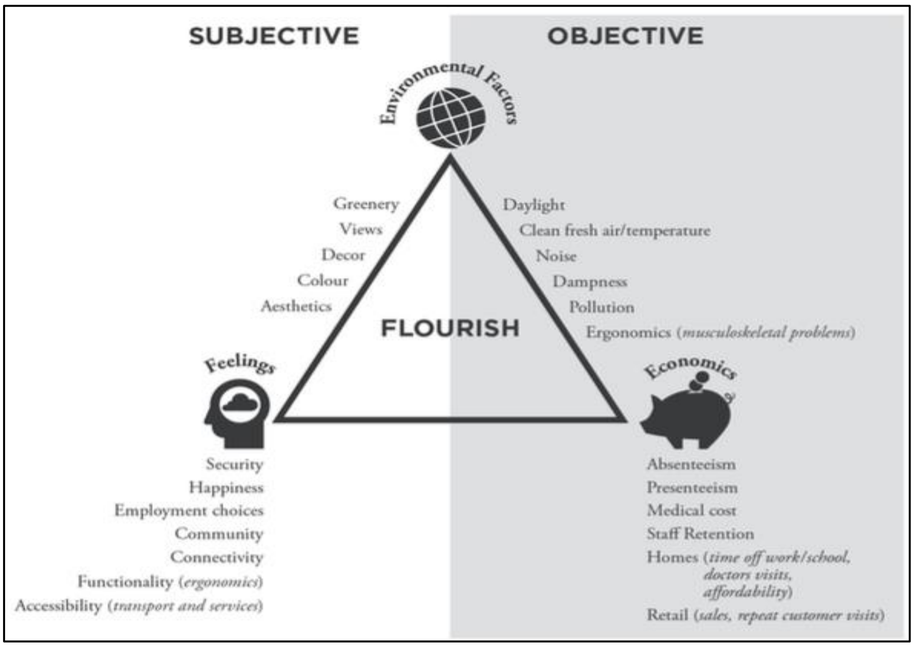


Fig. 16 - Flourish Model – Clements-Croome (2016)

The determinants of workplace well-being is suggested by Warr (2002) to depend upon job function and type and it relies upon many additional factors; task variety, location, goals, the physical space, personal control, the opportunity to flourish, status, contact and prospects, but organisational and personal factors are also present. The recent flourish model presented by Clements-Croome (2016) supports Warr's conclusions, but extends the principle to personal feelings, environmental and economic factors.

The performance model highlighted by Heerwagen (1998) and supported by Fogg (2009) attempts to bring these determinants into a single non mathematical equation, proposing the workplace has a significant role in supporting positive personal performance factors.

Performance = Motivation x Ability x Opportunity

Proposing seven basic infrastructures to create a positive workplace, Loftness et al (1997) also sought to demonstrate how the workplace would evolve using technology:

1. Fresh air and temperate control
2. Lighting control
3. Daylight and vistas
4. Privacy and quiet locations
5. Network access
6. Multiple data, power and ICT connectivity
7. Ergonomic furniture with environmentally sensitive finishes.

This occupant view of the workplace however is categorised differently by Wilson (1987) suggesting the occupant is not considered sufficiently important enough, and that the focus at an organisational level is upon economic efficiency. This may have been the case in 1987 and to a certain extent remains today, but the environment is changing. Wilson concluded that organisations view their buildings/workplaces as effective tools and assets proposing five alternative building/workplace views.

1. As containers with no respect to IEQ factors or their affect upon occupant performance. (Negative)
2. As prestige symbols rather than how effective the workplaces interact with users. (Negative)
3. As a vehicle for industrial relations promoting the view of health & well-being. (Positive)
4. As instruments of efficiency based upon rate of return of investment rather than for improving the welfare of staff. (Negative)
5. As an operational force reflecting business profiles - (Negative/Positive)

Focussing upon thermal comfort as primary IEQ issue as an example, research already confirms that temperature affects performance, concentration and learning. Fanger's (1970) definition of Thermal Comfort can be said to be true for IEQ factors;

"comfort is a condition of mind which expresses satisfaction with the environment", however, fundamentally comfort and well-being are difficult concepts to capture and define. An improvement in thermal comfort will increase motivation to work according to Cui et al (2013), and therefore if we increase motivation then we should increase performance.

2.1.12 – The Concept of Occupant Well-being

The theory of subjective well-being conceived as "something which makes your life go better" (Scanlon 1996) is simply not appropriate for the built environment. Huppert et al (2005) suggests well-being "as a positive and sustainable set of characteristics which enable individuals and organisations to flourish". Warr (2002) however proposes a psychological 3-D view of well-being suggesting that three parallel scales; *pleasure to displeasure; comfort to anxiety and depression to enthusiasm*. Steemers & Machanda (2010) proposes a further definition suggesting a further three dimensions of *health, comfort and happiness*. These inter-related parameters are proposed to lie on a spectrum between objective and subjective ends and can be either quantitive or qualitatively assessed. The complexity of the indoor environment is becoming clearer.

Well-being and the intelligent work environment proposed by Reijula (2011) proposes that the intelligent work environment must interact with and between users. It must also process and understand user requirements; react to user requests; be active, and provide autonomous functionality throughout the workplace experience. Reijula further comments that intelligent work environments must improve work flow and work productivity, and enhance the physical and psychological state of well-being. Passive and active workplaces will if designed and operated correctly deliver intelligent work flows and spaces. "Well-being in a network of places", research by Richert & Lehvila (2014) share in principle Reijula conclusions, but enhance the workplace system and network to include cognitive ergonomics and other aspects of personal fulfilment. They propose interaction with the environment and building aesthetics, connecting with the outside and inside environment as a major aspect for supporting well-being. Richert & Lehvila see the workplace as an enabler for well-being, but this must be retained within the holistic intelligent environment inclusive of flow and for maintaining an ultradian rhythm.

Putting people first and designing for health and well-being a research update from the British Council of Offices (2015) brought to life the concept of "Beyond Comfort".

Traditional comfort models are moving away from uniform IEQ characteristics to encourage more dynamic relationships (De Dear 2011). Aguila (2014) of Arup suggest that designers have a duty of care to ensure that occupants are provided with environments that encourage a healthier and happier existence. For organisations to be productive and successful they must encourage well-being states Clements-Croome (2006).

2.1.13 – The Next Step – Beyond Comfort

The Beyond comfort concept is an extension which incorporates incalculable factors which enhance productivity and performance. The results of a 2014 BCO Occupant Survey concluded Biophilia as an example, as a pleasing happiness factor and which is seen as fundamental component of well-being. Occupant responses were dissatisfied with the look of colours (80%), lack of greenery (64%) and lack of art (61%). Personalisation and integrated control is seen as another contributory factor to well-being and for improving occupant performance, allowing for on-demand changes in the local environment (Peters 2004).

Well-being, productivity and performance are fundamental to satisfying occupant and organisational aspirations, it would therefore seem sensible to embed strategies that fundamentally support improvements in productivity and performance. The Well-being Standard from the relatively new Well Building Institute is supporting this view, however, it appears to be a mere extension to the BREEAM type approach in the UK or the LEED certification process in the US. The development of such a standard that is measurable and provides metrics that can be compared and contrasted is a positive move forward. The World Green Building Council similarly encourages adoption of such strategies, buts adds that financial performance and subjective metrics need to be included.

It is quoted that an individual’s level of productivity is directly linked to IEQ factors (Bordass & Leaman 1997), however, performance is also subject to occupant comfort and well-being which exists across multiple framings of thermal neutrality, adaptive comfort, subjective well-being and social experiences (Chappell 2015). This combined and more holistic view of Chappell, suggests that a different systemic approach is required when assessing actual building effects. This suggests *“productivity”* may not be the ideal metric for use within commercial office environments. The adoption of occupant “*performance”* on the other hand may offer a more reliable and more realistic assessment method when assessing performance levels particularly when assessing the impacts of IEQ factors upon the individual. Developing a commensurate set of individual physiological attributes and by aligning workplace and personal performance measurements, it is anticipated that environments will begin to support more the personal sense of well-being and to improve levels of satisfaction so that people feel more productive.

2.1.14 – The Dynamic Relationship of IEQ Factors and Occupant

The Comfort of workers in office buildings: the European Hope project, sought to relate IEQ factors and perceived levels of occupant comfort. Perceived comfort is more than the sum or average of IEQ factor responses, within the HOPE project "comfort" was defined as being part of the term of health and was defined as; "*the indoor environment can be defined as healthy when the combination of its physical, chemical and biological properties are such that they do not cause illness, and that they can provide a high level of comfort for the intended activities of the occupant".*

The HOPE project was a EU part sponsored study to research the relationships between the building environment, integrated social factors and occupant personal factors, then assessing these relationship to that of perceived personal comfort. The study across 59 buildings and 5,732 respondents concluded that an individuals perceived health, and level of comfort is effected by various building factors as well as personal factors. The study used a questionnaire format, semi structured interviews and an inspection of each building, so contained a significant subjective element. No physiological occupant monitoring was provided. The questionnaire focused in six specific IEQ areas:

1. Air quality - movement, smell, stuffiness
2. Thermal conditions – too hot; too cold; comfortable
3. Noise – outside, building systems; overall
4. Vibration – building
5. Lighting – artificial; daylight; glare
6. Cleanliness – building; workplace

The project concluded and further recommended, that physiological monitoring is a key factor for understanding the relationships between buildings and occupants, and that it would be a significant step forward in developing effective workplaces (Bluyssen et al 2011).

The European OFFICAIR study 2011-2012 (Bluyssen et al 2015) studied 67 offices and collected 7,441 self-administered survey responses. The study focussed upon identifying health stressors associated with IEQ factors and comprised of field investigations, questionnaires and environmental monitoring. The research comprised of three complimentary phases; a general survey; physical and chemical measurements (VOC's) and an intervention study across nine of the selected buildings.

Fig.17 - Officair Research Methodology

Two 7-point survey scales were used; 1) a Likert bipolar scale to assess occupant IEQ responses e.g. too hot or too cold, 2) a 1-7 unipolar scale to obtain a satisfaction rating against the perceived IEQ factors.

In terms of health responses, each building occupant was questioned against the Building Symptom Index (BSI - Raw et al 1996) to assess how the individual felt when away from the building and when within the building. The BSI is based upon five particular symptoms; dry eyes, blocked or stuffy nose, dry irritated throat, headaches and lethargy. The BSI's for each building were calculated post the assessment of each respondents Personal Symptom Index (PSI), which is the number of symptoms reported by each individual. A further personal aspect associated with the Effort Reward Imbalance (ERI) calculated index, comprised of three psychometric scales associated with effort, reward and over-commitment (Siegrist et al 2004). *Effort* is measured by 5-factors which refer to demanding aspects of the work environment, were as *reward* is measured by 11 factors grouped into three primary components of esteem, job promotion and job security.

The OFFICAIR project for the first time used the PSI index model to compliment the IEQ factor analysis, as well as the more subjective elements of personal mood and self estimated productivity (Li 1998). This particular study did not conclude any direct relationship to well-being, or personal satisfaction, however, it did discover a consistent set of IEQ factors which were being experienced by end users and which had a negative response. Noise was a particular complaint as well as thermal complaints, while dry eyes and headaches were the most prevalent symptoms experienced. Overall 29% of respondents believed their perceived productivity was affected by IEQ factors when at their workstations, and a summary of complaints is noted below:

- 37% poor air quality – dry (47%); stuffy (38%)
- 36% overall noise particularly from within the local environment
- 31% temperature – too hot (15%); too cold (40%); air too still (48%)

The effects of indoor environmental quality upon the occupants perception of performance: A case study of refurbished historic buildings in Malaysia (Kamaruzzaman et al 2011) offers an occupants subjective opinion of the internal built environment. This particular study sought to gain an appreciation of “user satisfaction” and the associated “degree of importance” of various internal factors, and to determine if an illicit fingerprint existed across various these factors.

The study considered 22 individual IEQ factors to obtain a % user satisfaction score, terming the results as the buildings satisfaction fingerprint. The survey used a bi-polar 7-point Likert scale survey template to obtain quantified “user satisfaction score %” and degree of importance vote. The user satisfaction fingerprint were % rated, with the averaged importance scores ranked in terms of the number of averaged votes (Fig.18). Six buildings were surveyed three of which were office type environments.

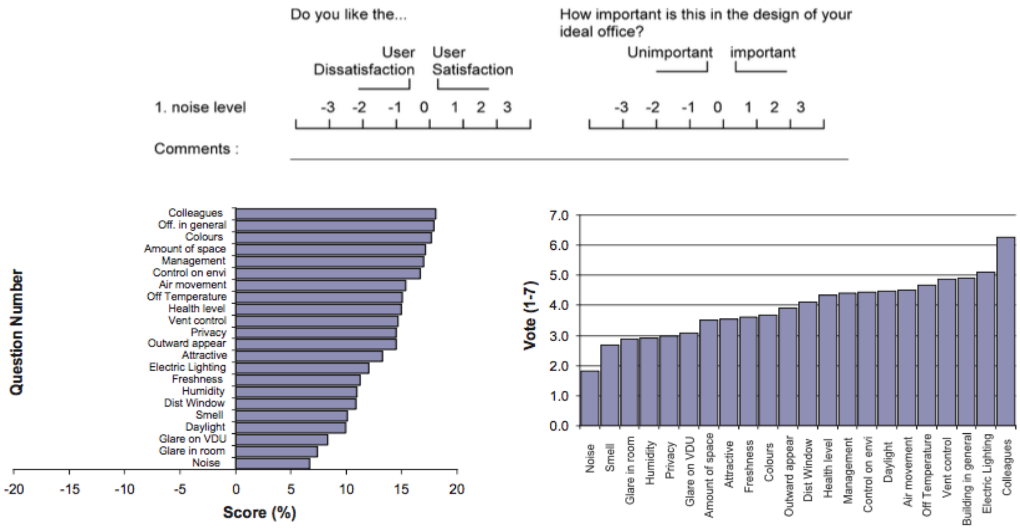


Fig.18 Kamaruzzman et al (2011) – User Fingerprint Responses and Degree of Importance Votes.

Surprisingly both sets of surveyed results showed no negative responses indicating either, the survey questionnaire may have been slightly biased, or the building performance perception by the occupant within these buildings was holistically good. However, it would be reasonable to expect a number of negative responses over a six building study. Interestingly when comparing the two sets of results, there appears to be a different level of expectation between perceived IEQ factor satisfaction scores and the average IEQ ranking of importance % votes. Adopting Principal Component and Factor Analysis to assess the factorability of the data, the study determined the existence of six primary component factors detailed within Table 5.

This particular study proposed that by feeding back lessons learned to designers and operators, and by offering building owners and end users the opportunity to benchmark their individual IEQ performance, then overall building performance and occupant satisfaction should improve.

IEQ Factor	**Component**						
		1	2	3	4	5	6
		Air Quality	Intrusion	Control	Appearance	General	Lighting
Noise	1		✓				
Artificial Lighting	2						✓
Daylight	3						✓
Glare (room)	4		✓				
Glare (VDU)	5		✓				
Window distance	6						
Temperature	7		✓				
Vent Control	8			✓			
Air movement	9			✓			
Freshness	10	✓					
Humidity	11	✓					
Smell	12	✓					
Health Level	13	✓					
Colour	14				✓		
Attractiveness	15				✓		
Environmental Control	16			✓			
Amount of space	17					✓	
Privacy	18					✓	
Colleagues	19					✓	
Management	20					✓	
General building	21					✓	
Appearance	22				✓		

Table 5 Kamaruzzamn et al (2011) – IEQ Factor Analysis and Relationship Matrix

The European Occupier Survey conducted by CBRE (2014/15) reported 67% of respondents are focussing upon new workplace strategies, retention of people and occupant well-being. A recent UK BMJ publication "*The sedentary office: a growing case for change towards better health and productivity*" (Buckley et al 2015) cited people working in offices spend 65-75% of their time sitting, and >50% of this time is prolonged and sustained. In the past 5yrs growing medical evidence supports a sedentary existence is linked to cardio-vascular disease, diabetes and some cancers, therefore how we interact with our workplaces is a primary concern for health, well-being and productivity.

Clements-Croome (2005), proposes a model for productivity that depends on four cardinal factors, personal characteristics & emotions, the social milieu and interaction, organisational features and building environmental factors.

2.1.15 – Health, Well-being & Satisfaction

With such concern surrounding real heath impacts and the need to develop well-being concepts that deliver positive health outcomes, we must review the quality aspects of buildings. Personal satisfaction is a characteristic of health & well-being, and using Kano's satisfaction theory (Fig.19), this demonstrates how personal satisfaction is subsequently affected by many other service performance factors within the environment (Kim & de Dear 2012). The subjective feeling of satisfaction is a known component of the overall feeling of well-being (Fig.20), and is defined by Heerwagen (1998); Herzberg (2003) and Speitzer (1995) as covering two broad well-being categories. The first category characterising the physical environment of the workplace, and the second category being the more subjective psychological sense of well-being based upon fulfilment of personal satisfaction. Previous studies have rarely independently assessed the physiological aspect of well-being, consequently, there exists a need to develop further this physiological category.

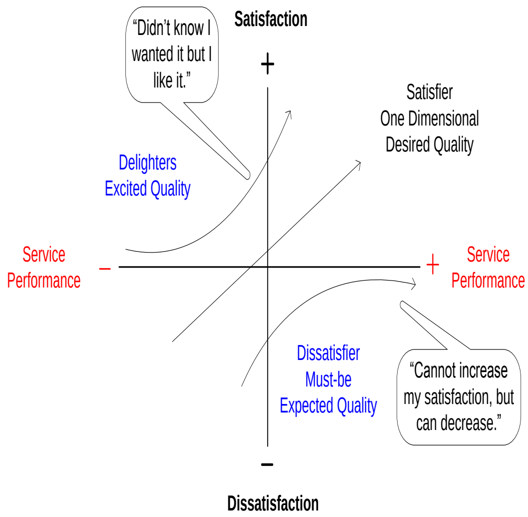


Fig.19 – Occupant Satisfaction v Performance Kim & de Dear (2012)

Fig.20 - Aspects of Well-being.

More recent research has focussed upon well-being as a defined "network of environments", preferring to support the workplace as the main stimuli in creating a perceived level of well-being (Richert & Lehvila 2014). This approach is only a sectional view of the overall IEQ system and in how it affects occupant comfort and well-being. However an alternative view suggests comfort and well-being possess two distinct elements (Chappels 2011). Firstly "Comfort" defined as a fixed property related directly to thermal neutrality as defined by Fanger (1970) or some other IEQ comfort factor; and secondly "Well-being" as a socio psychological paradigm associated with the individuals specific needs as classified by Maslow in 1943 and Herzberg 1968.

2.1.16 – The Impacts of IEQ Factors

The complex nature of IEQ impacts and their subsequent interpreted results are unique and complex, primarily as everyone has different needs and senses. A review of previous IEQ factor analysis (Frontcza & Wargocki 2010), demonstrated the diverse results across four key IEQ workplace factors; air quality; acoustic; thermal and visual conditions. The argand diagram (Fig.21) indicates the diverse responses obtained in one particular classroom study, demonstrating the difficulty in assessing a common approach to IEQ design and the resultant effects that may be expected.

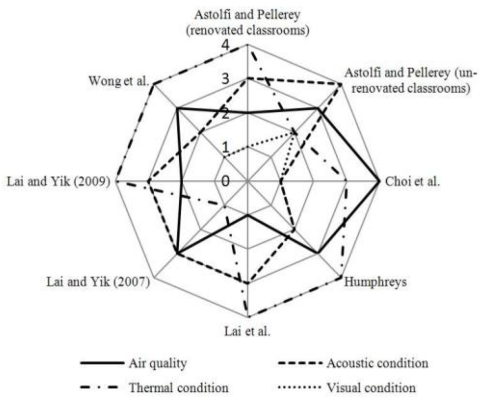


Fig. 21 - IEQ Research Results Frontczak & Wargocki (2010)

Building and occupant performance assessment is a complex subject responding to external affects, internal criteria and subjective stimuli (Hopfe, et al 2013). The recognition that many of the inputs whether they relate to specific comfort factors e.g. lighting; thermal acoustic, physical, IAQ, or indeed visual aspects, have in the past been premised upon post occupancy evaluation (POE) techniques using surveys, questionnaires and interviews. Workplace Quality Factors (WQF) however, possess a strong influence upon overall performance, consequently, IEQ & WQF factors have a fundamental relationships to affect occupant satisfaction, performance and productivity.

"Putting people first and designing for health and well-being a research update from the British Council of Offices (2015)", proposes we are moving beyond past views of uniform comfort factors, instead moving towards dynamic conditions (de Dear 2011). The reality is that designers will need to integrate the building with the occupant, and to develop dynamic response models to assess mutual performance levels.

2.1.17 – Defining Workplace IEQ Factors

The definition of IEQ factors provided by the US Green Building Council suggests IEQ encompasses the conditions inside a building which become defined as a result of the air quality, lighting, thermal conditions, ergonomics and their mutual effects upon occupants. The Centre for the Built Environment (CBE) at the University of Berkley however, assess IEQ factors as detailed in Table 6 Through the delivery of an extensive on-line POE survey over a 10-yr period, their assessment classified three levels in defining and for future research in IEQ factors; 1) a primary IEQ dimension; 2) a subset of elements; and 3) a specific section of questions relating to specific elements. Described previously within the introductory chapter, we begin to see how the perception of IEQ factors extends outside CBE's own definition, and that a

IEQ dimensions	Questionnaire items	Survey questions
Thermal comfort	Temperature	How satisfied are you with the temperature in your workspace?
Air quality	Air quality	How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odours)?
Lighting	Amount of light	How satisfied are you with the amount of light in your workspace?
	Visual comfort	How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?
Acoustic quality	Noise level	How satisfied are you with the noise level in your workspace?
	Sound privacy	How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbours overhearing and vice versa)?
Office layout	Amount of space	How satisfied are you with the amount of space available for individual work and storage?
	Visual privacy	How satisfied are you with the level of visual privacy?
	Ease of interaction	How satisfied are you with ease of interaction with co-workers?
Office furnishings	Comfort of furnishing	How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?
	Adjustability of furniture	How satisfied are you with your ability to adjust your furniture to meet your needs?
	Colours & textures	How satisfied are you with the colours and textures of flooring, furniture and surface finishes?
Cleanliness & maintenance	Building cleanliness	How satisfied are you with general cleanliness of the overall building?
	Workspace cleanliness	How satisfied are you with cleaning service provided for your workspace?
	Building maintenance	How satisfied are you with general maintenance of the building?
Overall satisfaction	Satisfaction with workspace	All things considered, how satisfied are you with your personal workspace?

Table 6 - Berkley Centre for Built Environment (CBE) IEQ Factor Analysis 2000 – 2010 On-line Survey Questionnaire

differentiation exists between what is a subjective POE assessment, and to what could be quantifiably and quantitatively assessed using physical measurement.

The results of the CBE survey (Fig.22) indicates the adjusted statistical value of the +ve and –ve impacts and how they range across overall perceived levels of satisfaction within the occupied space. The white bar indicates a +ve satisfaction reaction while the grey bar a -ve reaction. The regression coefficient represents the linear relationship between the two variables of satisfaction and dissatisfaction and is a multiple regression calculation assigning dummy variables to each IEQ factor in order to calculate the indicated results per factor.

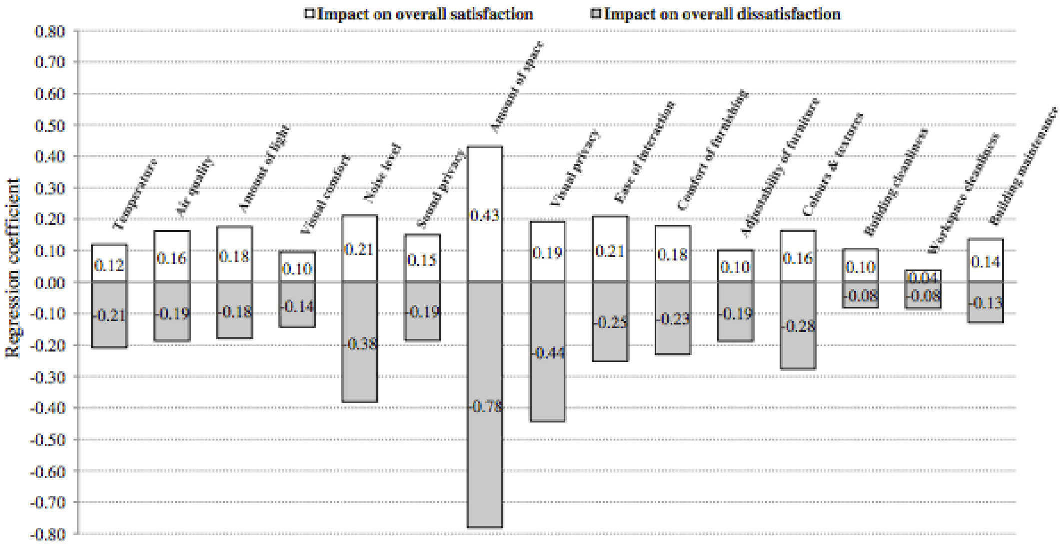


Fig.22 - Positive (+ve) & Negative (-ve) IEQ Satisfaction Relationship (Kim & De Dear 2012)

Rank	***Perceived*** performance is high	Perceived performance is low	Rank
1	***Amount of space****	***Amount of space****	1
2	***Noise level****	***Visual privacy****	2
3	Ease of interaction	***Noise level****	3
4	***Visual privacy****	***Colours & textures****	4
5	Comfort of furnishing	Ease of interaction	5
6	Amount of light	Comfort of furnishing	6
7	***Colours & textures****	***Temperature****	7
8	Air quality	***Adjustability of furniture****	8
9	Sound privacy	Air quality	9
10	Building maintenance	Sound privacy	10
11	Temperature*	Amount of light	11
12	Building cleanliness	Visual comfort	12
13	***Adjustability of furniture****	Building maintenance	13
14	Visual comfort	***Workspace cleanliness****	14
15	***Workspace cleanliness****	Building cleanliness	15

****Basic Factors*** (the rest are Proportional Factors).

Table 7 - CBE IEQ Factor Ranking – Kano's Satisfaction Theory (Kim & De Dear 2012)

Interestingly if we consider the ranking of these factors (Table 7) we observe that other than noise, the generally defined IEQ factors of thermal, lighting and air quality are not included within the top 5 factors in either the high or low results category. Kim & De Dear (2012) noted that ***Basic*** factors i.e. those predominately +ve or –ve possessed significant impact on satisfaction, while ***Proportional*** factors those both linearly +ve or –ve had little impact upon satisfaction. **Bonus** factors however, offered generally +ve increase in satisfaction and were seen as unexpected +ve factors towards the occupant. Kim and de Dear's (2012) study however found the existence of no bonus factors, the main conclusion being that all fundamentally ***Basic*** IEQ factors have either a positive or negative impact upon satisfaction, therefore can significantly effect levels of perceived satisfaction.

2.1.18 – The Concept of Happiness

An additional factor within the workplace which needs to be considered, is one that has received little attention to date but is becoming a more prominent factor within the overall feeling of well-being is the occupants enjoyment at work or level their of happiness. This is an important factor to understand, as happier employees tend to have a more positive attitude towards their job-task (Diener et al. 2002). Furthermore, it has been found that an enjoyable workplace can also help improve employee satisfaction (Meyer, 1999; Clements-Croome, 2011) their productivity and feeling of well-being.

2.1.19 – The Development of Practical IEQ Assessments

IEQ models require data aggregation to offer a summary of how workplaces are performing (Heinzerling et al 2013). These evaluations may be completed using physical measurements of the space, but should include subjective occupant surveys and interviews to assess the objective and subjective impacts. The purpose of such models is to classify and rate these objective and subjective responses by adopting a rating score. A literature review of existing studies (Heinzerling et al 2013) has provided some consensus of which IEQ factors should be measured and for what period of time and these are summarised below in Table 8.

With a lack of consensus on measuring protocols and each tool being used or interpreted differently, it is not possible at this moment to standardised IEQ measurements. Workplace IEQ studies by Cao et al (2012), Chiang et al (2001 & 2002) and Lai (2009) considered IEQ measurements in different ways and across different spatial needs.

Objective (Physical) IEQ Measure	Subjective IEQ Measure	IEQ Relationship Analysis	Suggested Measurement Requirements
Acoustic (dbA)	Simultaneous right now survey Expert Survey One time survey	Linear Regression Correlation Single variable regression Multivariate regression Sensitivity Analysis	1-wk continuous/site Seasonal monitoring 1; 5; 15min intervals 24hr continuous Close to user issues Spatial types 4 locations/area/room Adjacent users Data logging instrument Background levels External levels
Carbon Monoxide (CO)			
Carbon Dioxide (CO2)			
Particulates (PPM)			
Indoor Air Quality (IAQ)			
Lighting (Lux)			
Temperature (deg.C)			
Humidity (rh%)			
Volatile Organic Compounds (VOC's)			
Formaldehyde (HCHO)			
Air velocity (m/s)			

Table 8 - IEQ Factor Modelling Criteria & Statistical Analysis Relationships - Heinzerling et al (2013)

The dilemma therefore is to find a protocol and set of standard applications that can form the basis of any IEQ study, but be manipulated within a set of reasonable expected boundaries.

Part 2 – IEQ Standards

The approach to standardisation would appear to have responded to specific IEQ issues e.g. poor levels of IAQ, lighting, thermal comfort, noise etc., which is why we have today such a disparate collection of global standards and guidance documents. An extensive global IEQ standard literature search has concluded that no definitive single standard exists towards defining the discrete nature of IEQ factors or the potential affects they may have upon building occupants. Conversely however, and relative to health, well-being (wellness), satisfaction, performance or productivity, there are considerable amounts of existing research literature, published journals and reference books, but no single collaborative IEQ standard.

2.2.1 – The IEQ Standards Dilemma

There are however a number of inter-related standards focussing upon various aspects of the workplace environment and in particular towards IEQ aspects. They tend however, to be focused into specific workplace comfort areas e.g. thermal comfort, lighting; air quality and are primarily biased to matching comfort with energy efficiency (Fig.23). These inter-related supplementary type standards are predominantly based upon IEQ monitoring and the subjective psychological response of building occupants through survey responses, and they neglect the physiological responses which exist as a consequence of the relationship of the building and the occupant. A section of the mainly adopted IEQ standards are scheduled below within Table 9.

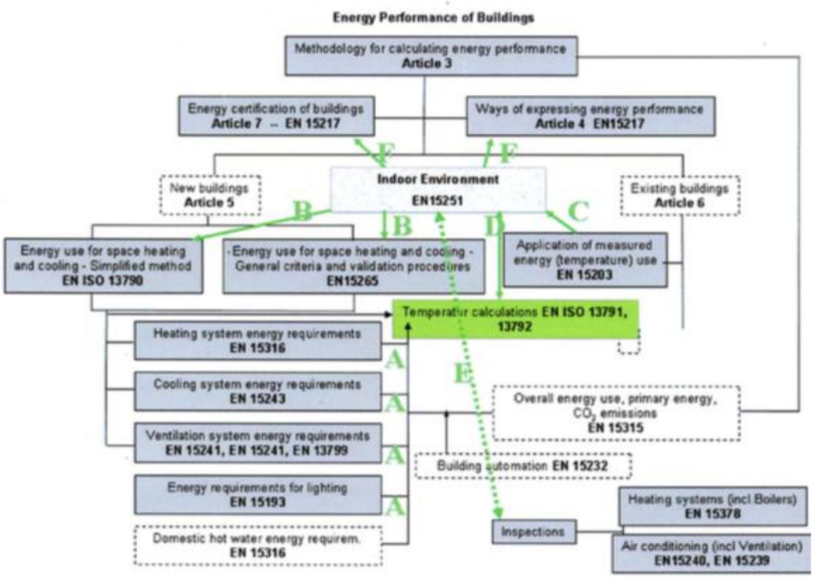


Fig.23 - EU Indoor Environment Standards Relationship Map

The US the joint developed ASHRAE/CIBSE Performance Measurement Protocols (PMP) Best Practice Guide supports the EU Standard EN15251 "Indoor environmental input parameters for design assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.(2007), however, the focus of BS EN15251 is to comply with the EU Energy Performance in Buildings Directive - EPBD (2010), which has the primary objective of energy saving within buildings.

The EPBD possesses the ability to directly affect IEQ factors as a consequence of focussing upon energy efficiency and therefore could impact occupant satisfaction, well-being and performance. Because BS EN15251 is a standard and primarily used for energy simulation and optimisation, there is little guidance on how to measure the effectiveness of IEQ factors or their affect upon energy consumption and interactive occupant behaviours. We musty recognise that buildings need not consume energy it is the behaviours, needs and specific business requirements that drive energy consumption.

The REHVA Indoor Climate Quality Assessment Guidebook addresses some of the IEQ and occupant relationship concerns, and focuses specifically around thermal comfort and IAQ. However, a specific European IEQ source guide remains unavailable. The US PMP guide offers an appropriate and accurate comparison of

IEQ factors following its joint production with ASHRAE, CIBSE and USGBC, but it has not yet been transferred into a regional standard.

IEQ Related Standards and Guidance Documents				
Description	Type	Origin	IEQ Factor	Primary Objective
ASHRAE – 55 (2010)	Standard	US	Thermal	Comfort
ISO 7730 (2005)		Global		
BS EN 15251 (2007)		EU	Thermal; Ventilation Lighting; IAQ; Acoustics	Energy, Efficiency & Comfort
BS EN 7730 (2005)			Thermal	Comfort
CIBSE Guide A	Guidance	UK	Controls, Lighting, Ventilation	Energy, Efficiency & Comfort
CIBSE Guide B; B1; B2; B3; B4				
CIBSE Guide F				Energy
CIBSE Guide M			Indoor air quality, thermal comfort influence, air distribution systems	Operation & Maintenance
CIBSE SSL LG 07/15			Lighting (offices)	Energy & Comfort
CIBSE SSL LG 07/15				
CIBSE TM 24			N/A	Productivity
CIBSE TM 40			Thermal; Ventilation Lighting; IAQ; Acoustics, Water Quality	Health

Table 9 - Review of Global IEQ Related Standards and Guidance

2.2.2 – Occupant Behaviour and the Energy Conflict

Energy use and occupant satisfaction researched by Agha-Hossein (2013) concluded poor workplace design significantly affected occupant satisfaction and in addition increased energy usage. Therefore when we consider these relationships, we must also consider the wider aspects of building performance. Holistically, therefore we must consider an embedded carbon view of building performance as well as operational energy consumption.

Research by Darby (2015) concluded buildings possess an inherent embedded carbon footprint determined by design and size. This conclusion supports our view, that occupation densities are a key design element to reduce external environmental impacts and are fundamental characteristics in reducing UK carbon emissions. Energy use and carbon management has become a significant issue to the UK strategic economy and significantly regulated under the UK Climate Act 2008. Understanding were occupant and building performance issues lie, will allow more intelligent buildings to be constructed and operated more efficiently, but importantly go some way to closing the current energy performance gap.

2.2.3 - BS EN 15251 (2007) – Indoor Environmental Input Parameters for Design Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics.

BS EN 15251 (2007) attempts to standardise IEQ factors into definable criteria but it does so focused upon building energy performance rather than occupant satisfaction, performance or heath & well-being. The standard addresses thermal comfort, IAQ, lighting and noise as cardinal occupant and energy related factors, and goes on to establish specific design criteria to achieve levels of acceptable occupant comfort. The standard also describes the methods required for the calculation of energy performance and audit requirements. BS EN 15251 was a consequence of the EU Energy Performance in Buildings Directive (EPBD 2002) which is now superseded by the 2010 update.

BE EN 15251 also recognises that poor IEQ factors can cost organisations more than the actual energy consumed within the building, but is unable to relate IEQ factors to any form of cost or performance relationship. Analysing the specific relations between related energy, IEQ or Well-being standards, it can be seen that conflicts between comfort levels exist. Table 10. Indicates the example of acceptable workplace CO_2 levels deemed acceptable for use within energy calculations.

BS EN 15251 Building Category & CO_2 Level BS EN 15251 – Energy Calculation > Outside concentration			
Outside CO_2 Levels 300-500 ppm		Allowable Increase above outside	Total Indoor (CO_2)
i)	High level of expectation and sensitivity	350ppm	650-850ppm
ii)	Normal level of expectation for new buildings and refurbishment	500ppm	800-1000ppm
iii)	An acceptable expectation for existing buildings	800ppm	1100-1300ppm
iv)	Expectations i) – iii) above and should be allowed for a short period	<800 ppm	

ASHRAE 62.1 (2010) CO_2 Guidelines for Indoor Environments and UK HSE Exposure Limits Guidance	
350-1,000 ppm	Concentrations typical of occupied indoor spaces with good air exchange
1,000-2,000 ppm	Complaints of drowsiness and poor air.
2,000-5,000 ppm	Headaches, sleepiness and stagnant, stale, stuffy air. Poor concentration,
5,000 ppm	Workplace exposure limit (as 8-hour TWA)
>40,000 ppm	Exposure may lead to serious Oxygen deprivation resulting in permanent brain damage, coma, even death.

ppm – parts per million; TWA – Time Weighted Average

Table 10 - Comparison of CO2 Levels Energy v Health Guidelines

Further examples for temperature, humidity and illumination levels are shown within Table 11, but again these relate to energy performance and do not related to occupant performance, motivation, satisfaction or health and well-being.

Building Category	IEQ Input parameter	BS EN 15251 Value	ASHRAE Typical Design Value	CIBSE Typical Design Value
ii)	Temperature	20-24^{o}Chtg 23-26^{o}Cclg	22-26^{o}C Summer 20-24^{o}C Winter	22-24^{o}C Summer 21-23^{o}C Winter
iii)		19-25^{o}Chtg 22-27^{o}Cclg		
ii)	Humidity	60%rh (dh) 25%rh (h)	30-60%	40-70%
iii)		70%rh (dh) 20%rh (h)		
ii)	Lighting	500lx; UGI 19; Ra 80		350-500lx; UGI 19; RA 80
iii)				
ii)	Noise	35-45 db(A)		
iii)				
ii)	Ventilation Rate (1persons/15m^2)	12l/s/person	8.5l/s/person (1/20m^2)	10l/s/person (1/10m^2)
iii)		7.5l/s/person		

Table 11 - Comparison of IEQ Factors BS EN 15251; US and UK Standards for Open Plan Offices

2.2.4 - BS EN 7730 (2005) - Ergonomics of the Thermal Environment

BS EN 7730 determines and interprets the degree of discomfort (thermal dissatisfaction) and predicts the general thermal sensation experienced by the building occupant. It interprets thermal comfort using a predictive vote (PMV) method, calculating a quantifiable percentage persons dissatisfied (PPD) value to assess whether the proportion of dissatisfied occupants is within an acceptable range. Using a 7-point bi-polar Likert thermal sensation scale (Table 12), the PMV is a calculated index value using the mean value of votes from a known surveyed group.

+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Table 12 - 7-point Likert Thermal Sensation Scale

The standard considers the concept of thermal balance (Fanger 1970) i.e. comfort being achieved when the internal heat production is equal to the loss of heat to the environment. In the well designed thermal space, the occupant thermoregulatory system will automatically modify skin temperature and sweat secretion to maintain an acceptable heat transfer and balance. This heat production and exchange is also reliant upon the bodies metabolic exchange rate (Met – w/m^2 – 1Met = 58.2w/m^2), clothing insulation (clo), air temperature (t_a), mean radiant temperature (t_r) air velocity (m/s) and the level of humidity.

The PPD is an index which establishes a quantitive prediction of those individuals dissatisfied with their thermal environment either too hot or too cold when voting either +3; +2 or -3; -2 on the thermal sensation scale.

The combination of PPD and PMV expresses satisfaction or discomfort of the body as a whole within its environment, however, local thermal discomfort can be caused resulting from specific issues e.g. draughts or vertical air temperature differences. A difference in temperature between ankles and head can cause discomfort through thermal imbalance and sensation. Causation can result from asymmetric radiant temperature differences from walls or floors demonstrating the complex nature of users expectations, IEQ factor performance and occupant responses.

BS EN 7730 (2005) Annex A provides a number of categories of thermal environment (ABC) and their expected relationships with PPD; PMV; Operative temperature; vertical air temperature difference; floor, ceiling, wall temperature differences and radiant temperature symmetry (Table 13)

Building Category	Whole thermal state		Local Discomfort			
	PPD (%)	PMV	Draught (DR) (%)	PD (%)		
				Vertical air difference (t^oC)	Warm or Cool floor	Radiant Asymetry
B (ii)	<10	-0.5 < PMV < +0.5	<20	<5	<10	<5
C (iii)	<15	-0.7 < PMV < +0.7	<30	<10	<15	<10

Table 13 – Categories of Thermal Environment PPD v PMV - BS 7730 (2005)

Table 14 indicates the maximum values for air temperature differences between ankle and head, floor surface temperature and radiant temperature asymmetry associated with different category buildings. The building category is defined as follows:

- B or C is defined as prescribed limits to be adopted to meet overall levels of occupant satisfaction (BS EN 7730)
- (ii) or (iii) is defined as the level of expectation of the occupant within the workplace i.e. high to low expectations of various workplace IEQ factors. (BS EN 15251)

Building Category	Vertical Air temperature difference °C	Floor surface temperature range °C	Radiant temperature asymmetry °C				Operative Temperature °C	
			Warm ceiling	Cool wall	Cool ceiling	Warm wall	Summer	Winter
B (ii)	<3	19 - 29	<5	<10	<14	<23	24.5 +/- 1	22.0 +/- 2
C (iii)	<4	17 - 31	<7	<13	<18	<35	24.5 +/- 2.5	22.0 +/- 3

Table 14 – Categories of Local Discomfort and Operative Temperature Scale - BS 7730 (2005)

The above tables indicate the complexity of the IEQ issues faced by designers. The spectrum of factors and the tolerances involved will not satisfy all building occupants, hence the %PD approach is a good method in satisfying the majority of building users.

2.2.5 - CIBSE Guide A – Environmental Design

CIBSE Guide A is considered the UK's primary technical resource for designers and installers of building services, especially low energy and sustainable buildings. Quality in environmental design has recently been added to the guide to consider the quality of the environmental design. Its inclusion identifies two specific requirements for achieving quality in building design; 1) the adoption of a holistic approach to the building design; 2) a system and process to assure the quality of the design calculations and decisions, i.e. a quality assurance procedure.

The guide acknowledges and satisfies current UK legislation, including the UK Building Regulations Approved Documents L and F (2013), and the requirements stipulated within the Energy Performance of Buildings Directive (EPBD). To an extent these regulations lean towards energy efficiency, but they do take into account the needs for occupant comfort at a fundamental level.

Specifically focusing upon workplace IEQ factors, CIBSE Guide A offers guidance upon - Thermal discomfort and potential health implications; humidity, air quality, ventilation strategies, the visual environment, water quality, electromagnetic effects of workplace services and equipment, noise, vibration, and the importance of health within communities and buildings.

2.2.6 - CIBSE Guide B; B1; B2; B3; B4 – HVAC

Building ventilation is the process by which fresh air is provided to workplace occupants and were concentrations of potentially harmful pollutants and/or contaminants are diluted or removed from the supplied air or space. Ventilation systems also provide a means for cooling a space and as a mechanism to distribute thermally conditioned air for both heating and cooling. It is a fundamental component of building services design and delivers a major part in supporting the comfort, health and productivity of occupants. However, ventilation can contribute significantly to a building's energy load and in some cases can account for 50 per cent or more of the total heating or cooling losses within a building.

CIBSE Guide B and its supplementary parts focuses on the following specific IEQ factors; contaminant control & filtration systems, fresh air supply rates, space ventilation for thermal comfort, humidity systems & their control requirements, ventilation to avoid interstitial condensation (SBS), air distribution within the space to avoid dis-comfort and noise emissions from building services equipment.

2.2.7 - CIBSE Guide F – Energy Efficiency in Buildings

CIBSE Guide F includes a specific section for 'developing an energy strategy', and reflects the changes to UK planning policy, which now include targets for reducing carbon dioxide emissions from new and refurbished buildings. The impact for IEQ related factors centers upon occupant behaviours, their needs and the levels of productivity that may impact the operational efficiency of the building. Energy management has moved up the corporate (CSR) agenda, part as a consequence of the Carbon Trust involvement and engagement with businesses, but also through the implementation of the CRC Energy Efficiency Scheme. The associated cost of carbon is focusing executive's minds to understand how energy is consumed and to what causes this consumption within an overall occupant led energy model.

The guide focuses upon the following IEQ factors; BEMS; ventilation strategies, occupant controls (lighting; heating), selection of light sources & luminaires, POE, occupant involvement, and the system maintenance to maintain system efficiencies.

2.2.8 - CIBSE Guide M – Maintenance Engineering and Management

Building designers set out to provide internal environmental conditions that enable business processes to function at an optimum efficiency level. However they must also provide a safe comfortable workplace for occupants to achieve their maximum performance potential and a healthy environment. Effective maintenance and operation is a key factor in ensuring this continues for the life of the building and therefore Guide M brings the importance of maintenance into focus educating building and property operators to understand their responsibilities and duties. It focuses designers to appreciate their role in providing installations that are safe, effective, economic to maintain & operate, and to be capable of delivering satisfactory performance for the building over their full lifespan.

The guide focuses on the following IEQ factors; occupant training and awareness, building user guides, achieving health & comfort (Indoor air quality, thermal comfort influence, air distribution systems, comfort during modifications to existing buildings, recommended assessment schedules.

2.2.9 - CIBSE Society of Lighting and Luminaires Lighting Guide (LG07/15)

CIBSE SLL LG07/15 emphasises the need to minimise energy use while maintaining a good visual environment for occupants. It keeps a balanced approach to design options by considering ceiling heights, direct/indirect lighting, up-lighting, and where lower ceilings exist recessed down-lighting.

Access to daylight in offices is known to be beneficial to the health and wellbeing of occupants (Baker and Steemers (2002). Where daylight can be used to provide illumination, designers should attempt to use this valuable lighting source and to integrate daylight with artificial lighting where appropriate (CIBSE SLL LG10/14). In order to do this, designers need to engage with building owners and developers at the earliest stages of a project. Regardless of the size and location of the office in question, lighting designers should seek to give the occupants an appropriately well-lit space in which to work.

Energy reduction in the built environment is a continuing challenge and lighting within offices is a major contributor to building energy demands. Careful selection of luminaires and their respective light sources along with appropriate controls can reduce energy demand, however, designers and installers can make a significant impact by talking to the people who will use the office. By understanding occupant needs and work profiles, a more tailored approach can be considered which delivers the lighting they need using the minimum energy. While the fixed desk remains a central part of office life, tablet and touchscreen computers are now commonplace and therefore lighting needs to adapt to a mobile workplace.

The need to accommodate this flexibility has brought significant challenges to lighting designers used to dealing with fixed scenarios, LG07/15 considers how to light office space for flexible use particularly where tablets, smartphones and touchscreen computers are being used.

LG 07/15 focuses on some of the specific key IEQ factors; the importance of understanding the office use, scale of illuminance, getting the most out of daylight, identifying the correct luminaire/lamp type to be used, colour rendering, control of lighting systems, and coordinating the lighting design to avoid glare (artificial and daylight). CIBSE SLL LG 10/14 – Day-lighting a Guide for Designers supports this guidance document.

2.2.10 - CIBSE Technical Memoranda TM 24 - Environmental Factors Affecting Office Worker Performance: Review of Evidence

TM24: Environmental factors affecting office worker performance, provides evidence of how the physical environment affects productivity in the workplace. It particularly focuses upon office knowledge based workers and includes performance measures, staff costs, psychological process, motivational aspects, and the effect of physical factors upon the occupant. It is generally a literature review of available research, however, provides a valuable in sight to the many facets that control and affect productivity.

2.2.11 - TM40: Health Issues in Building Services

The World Health Organisation defines good health as *“a state of complete physical, mental and social well being, not merely the absence of disease and infirmity”.* While the indoor environment should be managed to promote health and not merely to avoid illness, designers and operators need to ensure that the indoor environment does not contribute to ill health and/or undesirable stress.

The increasing importance of health issues for building services engineers needs to be emphasized, therefore the objective of TM:40 to inform and educate building service designers and managers concerning the health implications of the services for which they are responsible, and to give recommendations for limiting, or preferably avoiding adverse health effects. The content of TM:40 considers the possible health issues across a number of IEQ factors; thermal conditions associated with stress, humidity, air quality and ventilation, visual environment, water quality, electrical and electromagnetic issues and he acoustic environment. TM:40 is discussed further across Chapters 4-6.

Part 3 – Post Occupancy Evaluation

The use of post occupation evaluations defined by Loftness et al (2011) promotes occupants as human sensors and should be recognised as representing the inter-related nature of spatial, thermal, air, acoustic, and visual qualities. The human integrated sensor and the data gathered through POE survey techniques is a legitimate approach suggests Loftness.

2.3.1 – The Definition of Post Occupancy Evaluation (POE)

POE has many different definitions but can be defined as; "*the process of evaluating the actual and perceived performance of buildings after they have been built and occupied. The purpose is to reduce energy consumption, costs, and carbon emission as a consequence of operations, while simultaneously improving the comfort and acceptability of the buildings for its occupants*" (Nicol, Humphreys and Roaf 2012).

There are several definitions for POE (Hadjri and Crozier, 2009) suggested POE to be "*an appraisal of the degree to which a designed setting satisfies and supports the explicit and implicit human needs and values of those for whom a building is designed".*

(Friedmann et al. 1978), Preiser et al. (1988) described POE as *"... the process for evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time*", however, Wenner (cited in Cooper et al. 1991) explained that "*post occupancy evaluations in architecture are related to social and behavioural problems rather than to aesthetic issues*". Even the subject of POE is complicated with many definitions, however, they all generally the follow the same fundamental model as indicated within Fig.24.

Leaman (2004) claims it is essential to evaluate the performance of buildings as opposed to its simulation during the design phase, it is the building in use assessment that provides the evidence of how successful the design and operational phase of the building has been achieved. The book "POE of buildings" (Baird et al 1996) focuses upon building factors and the subjective influence imposed upon the occupant, however, Nicol and Roaf (2005), support POE based upon occupant comfort factors.

2.3.2 – Applying POE Techniques

In the US POE is termed building performance evaluation (BPE) and targets areas and factors to locate problems within the building (Prieser and Vischer 2005), it also allows the investigator to benchmark other similar buildings. In the UK The Usable Buildings Trust provides significant data and techniques for the delivery of POE surveys.

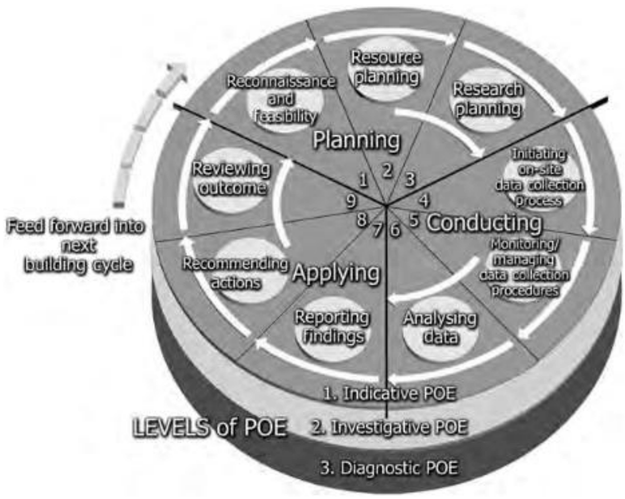


Fig.24 - Application and Levels of Post Occupancy Evaluation (POE) – Prieser and Vischer (2005)

Due to the variety of reasons for which POE surveys can be used, and the wide range of methods available, there is no standardised methodology or definition for POE (Bordass, 2003). However, according to Cooper (2001), any POE can be used as a management tool for providing feedback about a buildings performance, particularly in relation to business efficiency and productivity. It can also be used as a design tool to feedback performance data into the design of future buildings. They are also an opportunity to benchmark and compare a buildings performance against other similar buildings of which performance analysis is the main part of the POE process. Assessing POE performance relies upon a number of technical, behavioural and functional aspects within the environment to be considered (Cutler and Kane, (2009).

The ***technical*** element of the study considers the buildings IEQ factors, the physical parameters of noise, lighting, temperature, humidity, air quality etc., and relates these factors to the perceived comfort levels provided by the building. The ***behavioural*** study assesses the building in terms of occupant satisfaction and whether the building supports the occupant's expectations. The ***functional*** study evaluates workplace quality factors (WQF), the private and shared spaces, furniture, general workplace services, the environment etc., and to what extent the WQF's support the occupant's activities in the building.

It would appear that there are not only different reasons for conducting POE, but there are also different methods to be chosen based on the reasons for why the investigator is conducting the evaluation (Riley et al 2009). The three approaches when conducting POEs are summarised below within Table 15. (Preiser, 1995).

Post Occupancy Evaluation Overview					
POE Method	Analysis Type	Timescale	Applied Methodology	Survey Output	Additional Aspects
Indicative	Behavioural Functional	1-5 days	1:2:1 Structured Interviews; Meetings with occupants; building inspections	Interpreted report; photos and transcribed interview; feedback notes.	Generalised POE does not take into account all occupants; single building
Investigative	Technical Behavioural Functional	1-6 months	1:2:1 Structured Interviews; Meetings with occupants; building inspections; Questionnaire surveys; Physical IEQ measurements	Interpreted report; photos and transcribed interview; feedback notes; empirical data analysis	More in depth can cross more than one building and can be used as a benchmark tool
Diagnostic	Technical Behavioural Functional	1-12 months	1:2:1 Structured & Semi Structured Interviews; Meetings with occupants; building inspections; Questionnaire surveys; Physical IEQ measurements	Interpreted report; photos and transcribed interview; feedback notes; empirical data analysis	More in depth can cross more than one building and can be used as a benchmark tool; in-depth trend analysis of collected data

Table 15 - A Review of Standard POE Methodology, Content and Outputs

Prieser (1988) explained that POEs are divided into three phases: the planning phase were the need is established and how to conduct the process; conducting the survey, what method and analysis techniques to adopt; and the application, phase lessons learned and fed back into the design, construction and operational phases of building ownership.

In developing a specific survey approach, a review of currently available POE survey tools and methods was conducted and the main proprietary POE occupant evaluation tools are summarised within Table 16.

Typical Building Evaluation Tools		
Survey Name	Type	Comments
Building Use Survey (Arup) - UK	Benchmark	Benchmarks to a large building data set an occupants overall assessment of satisfaction
SPeAR (Arup) - UK	Sustainability Assessment	Integrated decision making tool used to assess projects designs through to operation
Leesman Index (Leesman) - UK	Benchmark	Benchmarks to a large building data set an occupants overall assessment of satisfaction. Provide an overall LMI index rating score for building performance.
BPE (BSRIA) - UK	Performance	Evaluates building in use performance – forensic walk through report; energy survey; occupant satisfaction
BREEAM (BRE) - UK	Sustainability Assessment	Holistic project review design through to operation. Assessment of design quality against performance in use.
Well Building Standard (Wellness Institute) - US	Performance	Adopts scorecard method to assess the occupants overall feeling of well-being
LEED (USGBC) - US	Sustainability Assessment	US equivalent to BREEAM - Holistic project review design through to operation. Assessment of design quality against performance in use.
CBE IEQ (Berkely University) - US	Benchmark	US equivalent to BUS. Benchmarks to a large building data set an occupants overall assessment of satisfaction
NABERs (NSW Office of Environment and Heritage) - Aus	Sustainability Assessment	Rating system -measures environmental performance of buildings and their impact on the environment.

Table 16 - Schedule of Typically (UK) Applied Evaluation Survey Tools

2.3.3 – A Comparison OD IEQ & POE Assessment Tools

The most widely used IEQ assessment tools are the US CBE and UK Building Use Study (BUS) tools which include subjective POE questions as well as objective physical IEQ attributes. Other prominent surveys used for POE include the

Workplace Performance Index - WPI developed independently by Gensler (2007) and the Leasman Index (2010), however, both tend to focus primarily on the subjective architectural workplace factors rather than more physical type of IEQ factors. The interpretation of all four of these tools is left to the individual circumstances at the time of any review and there are only limited guidelines in their application and similarly in how the results should be interpreted.

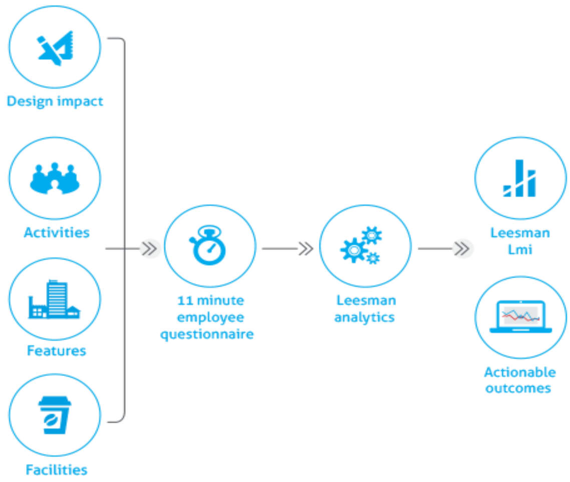
2.3.4 - Building User Survey (BUS) – Arup

The original method of evaluating occupant satisfaction developed by Adrian Leaman in 1985, the tool uses a large database of similar buildings producing a performance and benchmark rating associated with occupant satisfaction. Designed to extract information from as few questions as possible, respondents are asked to rate performance on a 1-7 "Satisfactory" scale. Designed to improve the occupant experience and optimise building performance levels, the tool captures quantitative and qualitative feedback across 45 key variables e.g. thermal comfort, ventilation, indoor air quality, lighting, personal control, noise, space, design, image and needs, and twelve summary variables to provide a snapshot of overall building performance. The use of the BUS tool however, constrains the user as it adopts a fixed set of questions enabling only a benchmark rating to be achieved. Limited flexibility is offered, and it does not allow bespoke building alignment within the survey questionnaire or allow potential issues to be uncovered. Interpretation of the results is also at the discretion of the survey recipient as the report is presented within a rigid benchmark framework. However, if comparative building performance benchmarking is required, then the BUS tool is an excellent POE method.

2.3.5 - SPeAR – Sustainable Project Appraisal Routine – Arup

An Arup developed and maintained project decision-making tool, it communicates outcomes visually through a unique argand type diagram post SME analysis of the project. An integrated set of indicators based on global sustainability standards, SPeAR appraises projects holistically across many and varied characteristics. The tool generates a robust and auditable set of tabulated input data from project appraisal right through to design and operation, and although the tool is comprehensive, it is holistically a sustainability tool providing predictive building and occupant performance ratings. Consequently, it does not focus effectively upon the specific IEQ workplace, it is ostensibly a sustainability assessment tool rather than an workplace occupant evaluation tool.

2.3.6 - Leesman Index (LMI)



Similar to the Arup BUS POE tool, the Leesman Index seeks to benchmark performance within its own and extensive building data set. The delivery of the POE study is based around a standard workplace survey questionnaire and template, which is an 11-minute e-survey, issued to each employee. The overall objective of the Leesman survey, is to improve the occupant experience and to optimise building performance, and it does this by calculating within its own analytics package, a functional & effectiveness score rating (LMI). The survey provides and benchmarks levels of occupant satisfaction and building performance based upon the constantly expanding data set. The LMI rating score is biased towards an "indicative survey type and it does not offer any consultancy interpretation of the data, it is simply a view of the analysed raw data presented as a property performance score and satisfaction rating.

2.3.7 - Building Performance Evaluation

Building Performance Evaluation (BPE) is an evaluation process developed by BSRIA. It was developed for evaluating the performance of a building using Post Occupancy Evaluation (POE) as one of its major parts in the analysis. It can be carried out in new, existing and refurbished domestic and non-domestic buildings, and can be integrated into BSRIA's soft landings model, helping to deliver effective and efficient buildings. The BPE process, and its subsequent associated activities, can be applied in any one of the project stages listed below, and can help significantly to inform either the project development, enhance its delivery, optimise system performance or provide user feedback to the building facilities team. The survey is a bespoke survey and tends to be delivered using an investigative POE approach.

1. Concept and Design stage
2. Construction stage
3. Pre-occupancy stage
4. Post-occupancy evaluation (POE) stage

BPE allows the person conducting the POE to evaluate the performance of different components and aspects of a building which are listed below:

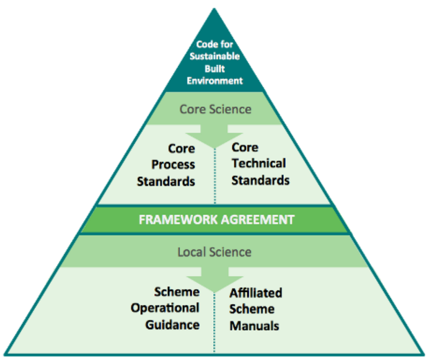
1. Building fabric
2. Building services and controls strategies
3. Energy, fuel and water use
4. Hand-over and commissioning processes
5. Occupant satisfaction
6. Occupant comfort

Using a bespoke survey format, the BSRIA POE approach within the holistic BPE model, evaluates the building in use and is focused on 3 key aspects:

1. Forensic Walkthrough – inspection of building's operation
2. Building Energy Survey
3. Occupant satisfaction – survey and interviews of building users

The approach uses soft data collection techniques to obtain feedback from building users, enquiring how well the building is working to satisfy user expectations and to assess if users are comfortable within their environment. Structured interviews, surveys and questionnaires are used to provide an Insight into user behaviour.

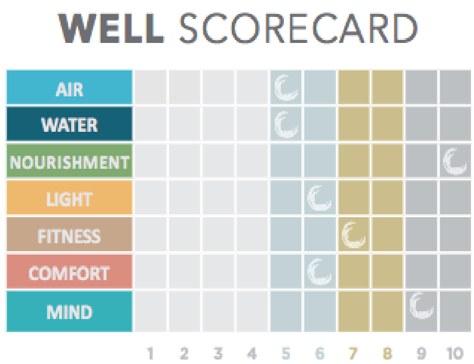
2.3.8 - Building Research Establishment Environmental Assessment Method



Abbreviated as the better-known BREEAM assessment tool, BREEAM is part of The Code for a Sustainable Built Environment which is a strategic international framework for sustainability assessment of the built environment, also known as The Code. The Code consists of a set of strategic principles and requirements which then define an integrated approach across the design, construction, management, evaluation, and certification of the environmental, social and economic impacts across the full life cycle of the built environment. The Code is interpreted through a Core Technical Standard and a Core Process Standard, both supported by Core Science. Similar to the Arup SPeAR sustainability tool, the POE element within BREEAM is a tailored solution using occupant & client consultation, interviews and surveys. The applied survey investigates comfort factors, reviews productivity, overall performance, and motivational staff issues. Occupant experience, user satisfaction within the amenities, the building image and its layout, the environmental monitoring of temperature, noise, light, air quality, ventilation, humidity are also collected. Overall the BREEAM tool assesses the sustainability of the building, it measures and demonstrates environmental performance of a building in use, and it articulates occupant and building performance feedback. It is however a much larger assessment tool and not specifically POE tool kit.

2.3.9 - Well Building Standard

The Well Building standard (WBS) or Wellness standard is the latest of a suite of standards attempting to provide a benchmark assessment of how well a building is performing for its owner/operator and the occupant. The WBS is administered through the International WELL Building Institute (IWBI) delivered and certified by Green Business Certification Inc. (GBCI) withinin the US, and who administer the US LEED certification program. Focused exclusively on human health and wellness and premised on medical input, the WBS sets performance requirements across seven categories (Fig. 25). WELL certification is based around performance values and requires upon passing a pre-determined score in each of the seven categories. The WBS is composed of over one hundred features (questions) that are applied to each building project, and each feature addresses particular issues that may impact health, comfort and even the knowledge base of the building occupants.



CONCEPT	PRECONDITIONS		OPTIMIZATIONS		CONCEPT SCORES
	APPLICABLE	ACHIEVED	APPLICABLE	ACHIEVED	
Air	12	12	17	3	5
Water	5	5	3	0	5
Nourishment	8	8	7	6	9
Light	4	4	7	2	6
Fitness	2	2	6	3	7
Comfort	5	5	7	2	6
Mind	5	5	14	12	9
Total and WELL Score	41	41	61	29	7

TYPOLOGY	PRECONDITIONS	OPTIMIZATIONS	TOTAL
New and Existing Buildings Certification	41	61	102
New and Existing Interiors Certification	36	64	100
Core and Shell Compliance	26	30	56

Fig.25 - Well Standard Scorecard and Question Index

2.3.10 - CBE IEQ Survey

The Berkeley Institute IEQ POE survey is a web based e-survey of 10-mins duration and comprises of 8 Core question areas - acoustic quality, air quality, cleanliness &

maintenance, general comments, lighting, office furnishings, office layout, and thermal comfort. Optional survey areas arte also available covering accessibility, building and grounds, commute, conference and training rooms, day-lighting, maintenance service, office support equipment, operable windows, raised floor and floor diffusers, restrooms, safety and security and way-finding. The survey tool is similar again to the Arup BUS benchmarking tool and can be said to be an investigative survey type. The CBE IEQ survey facilitates performance benchmarking, but does not provide any interpretation of the results and remains subjective to building occupant survey responses.

Chapter Summary

This chapter has considered the extremely wide subject area of IEQ factors and their relationship between building occupants and the workplace in which they work. Part 1 of this chapter considered the relevance and provision of existing research, seeking to clarify the many components associated with IEQ factors and the relationship with building occupants.

In reviewing existing research, it is relatively clear that many personal and physical interactive aspects exist to cause an impact to the building occupant. The separate approaches of occupant satisfaction, well-being, productivity, happiness, motivation, performance each has a different definition and meaning. Research has yet to decide which if at all any of these approaches are a suitable metric that can be taken forward into an enhanced POE model, and although some of these approaches are inter-related, they perhaps need to fit within a hierarchy of needs to enable the overall feeling of well-being to become the adopted rated metric.

Within Part 2 of this chapter, a review of IEQ standards was completed, to assess the how they might be applied within a new ePOE model. The conclusion of this part of the review, proposes that no single IEQ standard exists which focuses specifically towards defining an accepted performance metric, either for the building or occupant or the workplace. It was also noted that global differences exist between accepted technical standards. Regional differences will naturally exist, but it is clear that a standard model could be developed to rationalise the many subjective definitions. Additionally it would be useful to determine a globally accepted performance metric and to clarify what is actually needed to subjectively and objectively analyse workplace performance.

Finally within Part 3, a review of existing POE tools and models was completed. Similar to the issue that no single accepted IEQ standard exists, there are many different types of available POE tools, some offer benchmarking solutions and others offer investigative or diagnostic options. Each specific building assessment will be different, consequently the selection of a POE tool is extremely important, however the key element to any POE is the nature of the output and to what use the POE results will be utilised. Most POE surveys are cross sectional at a point in time, longitudinal surveys take up time and are disruptive, so a new approach may be required within todays and future intelligent buildings.

The development of an enhanced ePOE model requires the assessment of existing research, application of existing IEQ standards and the knowledge that existing POE's are different and therefore may need to be challenged. Recognising that the objective physical environment and occupant physical responses may need to combine into an active feedback model, Chapter 3 builds a research methodology to discover if occupant physical responses can actually be connected to overall workplace performance factors. If by connecting the occupant as a sensory agent to the building, and by the occupant understanding more intimately their workplace environment through mutually inclusive feedback, then an opportunity may exist to affect the overall subjective feeing of well-being.

Chapter 3 – Research Methodology

3.1 Introduction

This chapter illustrates the methods, concepts, software tools and the specific measuring equipment selected to conduct the research project. The research framework described within this chapter sets out an holistic approach for the development of an enhanced post occupancy evaluation (ePOE) feedback model, and has been developed following a detailed review of applicable IEQ literature. Set within two similar naturally ventilated workplaces, the project focuses upon assessing the affects measured IEQ factors have upon the physiological responses of the occupant, and subsequently considers how these affects can be interpreted into a future integrated Building Agent Model (iBAM).

3.2 Defining a Research Approach

In defining a research framework, it was recognised that various approaches would need to be adopted, both within and across a theoretical and applied research continuum (Fig.26). Research is seen as a systematic means of problem solving, and is considered to comprise of 5 key process characteristics (Tuckman 1978):

1. A systematic research process
2. Logical data analysis
3. Empirically evidence based data collection
4. Reductive generalisation - Reducing complex problems into smaller problems
5. Replicable methodology for future research opportunities.

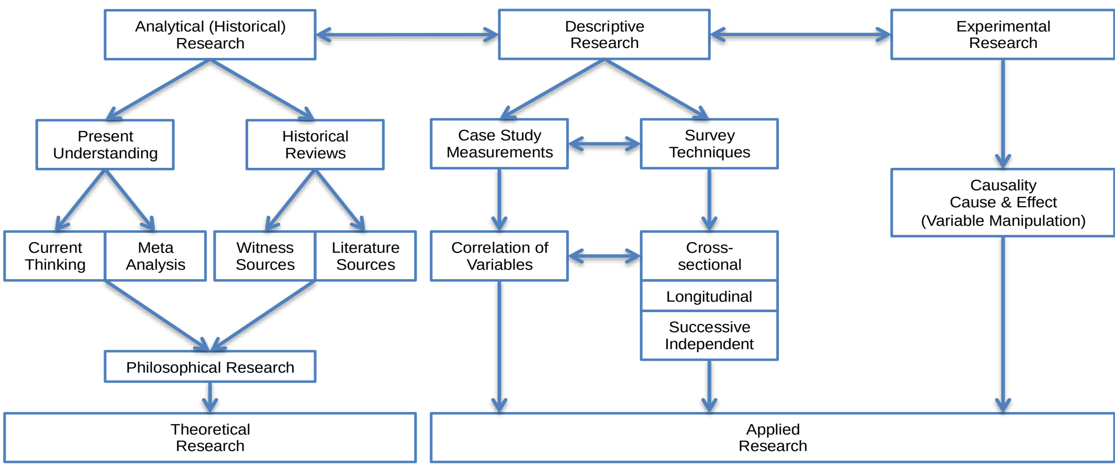


Fig.26 - Research Design Continuum – Developed from Tuckman (1978)

3.3 Research Framework

A comprehensive research plan and a robust framework for data collection and analysis has been provided to achieve the research aim (Bryman 2012), and the following sections described this approach in detail. In support of our research hypothesis (Chapter 1), both *Qualitative* and *Quantitive* research methods have been adopted, and although seen as two different research methods, both methods have been mutually inter-connected ***(triangulation)*** to create an objective view of the collected and analysed data (Creswell 2009). Based upon previous building IEQ monitoring approaches, this research model also uses an innovative *"experimental"* approach to collect extensive empirical IEQ and physiological data, adopting a non-intrusive passive presence within the monitored workplaces.

3.4 Qualitative & Quantitative Methods

The research uses two quantitative survey techniques and one qualitative semi structured interview technique applied within a descriptive research framework. In addition to the survey and interview techniques, empirical IEQ factor and occupant (volunteer) physiological measurements were collected at both research sites.

3.4.1 Quantitative Research Method

A quantitative research strategy aims to assess pre-defined theory from emerging data and often involves hypothesis testing. It minimises the inference of the research engineer by using data, however, it requires closed data responses from which data can be statistically analysed and/or correlated (Sapsford 2006). It also facilitates the generation of statistical output resulting from surveys and measurement. Quantitative research facilitates a number of accepted statistical standards to be adopted within such an approach, for example the number of respondents required to establish a statistically significant result (Goddard & Melville, 2004). Although this research approach is informed by a positivist philosophy, it can also be used to investigate a range of research data and other research philosophies.

3.4.2 Qualitative Research Method

Qualitative research seeks to provide new novel theory and to an extent the research engineer becomes part of the study through participation in interviews and through measurements. It also facilitates open survey and questionnaire responses to stimulate new lines of inquiry, information and feedback. (Denzin & Lincoln 2005).

Using interviews, survey responses and continual literature reviews, a qualitative method also explores attitudes, behaviours and experiences within groups, allowing the researcher to discover other experiences and knowledge which might nor ordinarily be obvious. The qualitative approach is drawn from the constructivist paradigm (Bryman & Allen, 2011), however, this approach requires the researcher to avoid imposing their own views on the meaning of the subject under investigation (Banister et al, 2011).

3.5 Developing a Research Project Framework

Determining a research strategy commences with understanding and having a vision of the data that needs to be collected and analysed. Although there is no typical framework to solve every research project, the RE is free to construct a research strategy based upon 1st principles, incorporating the necessary tools in its delivery. A typical view of research strategies (Fig.27) has allowed the RE to structure the project framework (Fig.26) into a discrete project delivery strategy.

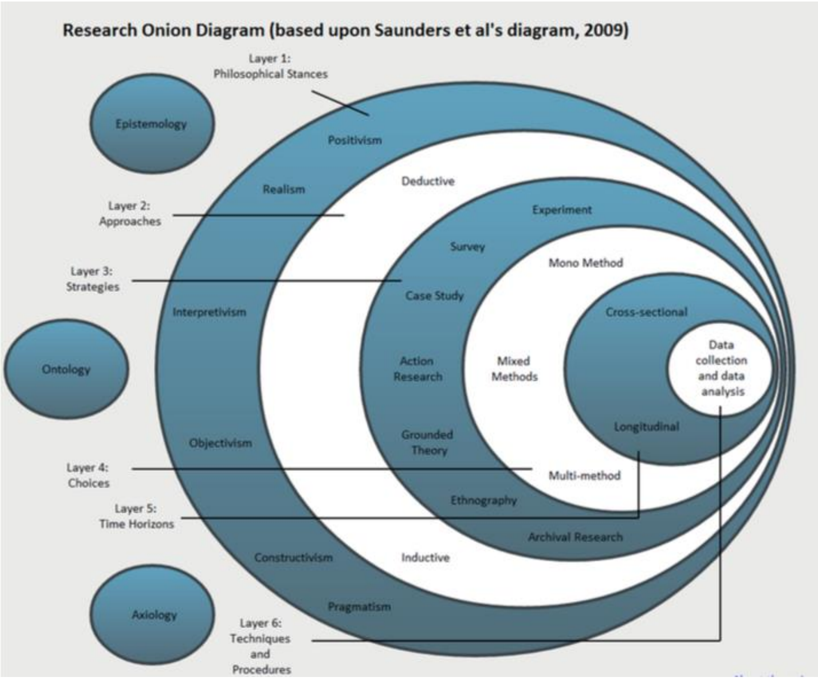


Fig.27 Strategies & Methods of Research – The Research Onion (Saunders et al 2009)

3.6 The Research Process

As the hypothesis of the research project was to determine a relationship between multivariate criteria, the RE studied the methods and approaches presented by Saunders (2007). Realising early in the project inception, it was clear that significant amount of data collection and analysis was to be required, therefore it needed to be coordinated carefully and accurately using a set of systematic steps (Fig.28).

Firstly, the research project or philosophy requires definition thereby creating the starting point for the appropriate research approach which becomes the second step. Within the third step the research strategy is adopted and in the fourth layer we identify the time horizon sectional or longitudinal study. The fifth step represents the stage at which the data collection methods are actually identified. The benefits of the research onion and the layered step through, is that it creates a series of stages under which the different methods of data collection can be understood and managed, and illustrates the steps in which a logical study can be performed.

3.6.1 Philosophy of a Research Project

A research philosophy aligns itself to the research hypothesis, the problem being investigated (Bryman, 2012), and is the underlying definition of the nature of knowledge being developed. The assumptions created by a research philosophy provide the justification for how the research will be undertaken (Flick, 2011), however, these philosophies can differ depending upon the goals of the research and on the best way that it might bets be achieved (Goddard & Melville, 2004). These are not necessarily at odds with each other, but the choice of research philosophy will be defined by the type of knowledge being investigated within the project (May, 2011). Therefore, understanding the research philosophy can help explain the assumptions inherent in the research process and how this fits within the methodology being used.

3.6.2 Research Approaches

Two types of approach exist: the deductive approach and the inductive approach.

1. The deductive approach develops the hypothesis or hypotheses upon a pre-existing theory and then formulates the research approach to test it (Silverman, 2013). This approach is best suited to contexts where the research project is concerned with examining whether the observed phenomena will fit with expectation, and is generally based upon previous research output (Wiles et al., 2011).
2. The inductive approach, is characterised as a move from the specific to the general (Bryman & Bell, 2011), and uses observations as the starting point for the research. The researcher looks for patterns within the collected data

(Beiske, 2007), however, within this approach there is no framework that initially informs the data collection, therefore, the research focus can then be formed after the data has been collected (Flick, 2011).

3.6.3 Research Strategy

The research strategy sets out a vision of how the researcher intends to carry out the work (Saunders et al., 2007). The strategy can include a number of different approaches, such as experimental research, action research, case study research, interviews, surveys, or a systematic literature review, or it can include a mixture or all of these strategies (methods).

3.6.3.1 Experimental Research Method

This refers to the strategy of creating a research process that examines the results of an experiment against the expected results (Saunders et al., 2007). It can be used in all areas of research, and usually involves the consideration of a relatively limited number of factors (Saunders et al., 2007). The relationship between the factors are examined, and judged against the expectation of the research outcomes.

3.6.3.2 Action Research Method

Characterised as a practical approach to a specific research problem within a community of practice (Bryman, 2012), action research involves examining practice to establish if it corresponds to the best approach. It generally involves reflective practices, which is a systematic process by which the professional practice and experience of the practitioners can be assessed and used.

3.6.3.3 Case Study Research Method

Using a case study method of a single study site or comparative group of sites, this method seeks to establish where key features may exists, and further seeks to draw generalisations (Bryman, 2012) from within the wider study area. This approach offers an insight into the specific nature of any group/s, and can establish the importance of context within the differences between cases (Silverman, 2013).

3.6.3.4 Grounded Theory Method

A qualitative methodology, Grounded Theory uses an inductive approach to assess if patterns exist within data and/or from the study being undertaken (May, 2011). For example, interview data may be transcribed, coded and then grouped to the common factors exhibited between respondents and between sites, however, research outputs are derived fundamentally from the completed research, rather than from data examined to establish if it fits within existing frameworks (Flick, 2011).

3.6.3.5 Surveys Method

Surveys tend to be used within quantitative research projects, and involve sampling a representative proportion of the population (Bryman & Bell, 2011). The surveys produce quantitative data that can be analysed empirically, and are most commonly used to connect variables between different types of data.

3.6.3.6 Ethnography Research Method

This method involves the close observation of people to examine their cultural interaction and their meaning (Bryman, 2012). Using this process, the observer conducts research from an observatory perspective, and then aims to understand the differences of meaning and the importance of their behaviours from their own perspective.

3.6.3.7 Archival Research Method

Conducted from existing materials, this form of research involves a systematic literature review to examine the existence of patterns, and to establish the sum of knowledge available within a particular area of study. It can also be used to examine the application of existing research to a specific problem (Flick, 2011). Archival research may also refer to historical research where a body of source material is mined in order to establish results and information.

3.7 Selecting a Research Process

Assessing the difficulties of field research within real workplace environments, a cross sectional approach was the preferred selected option. Undertaking longitudinal surveys and measurements in the opinion of those involved would significantly intrude on the workplace efficiencies and was therefore rejected by both research sites. Having assessed the requirements for surveys and field measurements a mixed-method approach was selected allowing the RE to cross connect between various collected data sources and to provide a level of flexibility in selecting relevant research techniques.

Although the research adopted both a deductive and inductive research strategy approach, the RE did not consider an ethnography strategy was relevant to the project and was therefore rejected. However, having adopted a mixed-method approach in the collection of empirical field measurements and applied survey data, the remaining strategies (methods) were considered appropriate and adopted.

3.7.1 Research Structure

Inclusive of a holistic approach, the overall research structure (Fig.28) sets out a staged and sequenced view of the methods adopted and how they were applied.
This staged approach, provided five discrete data collection work streams, and four discrete areas of data analysis prior to discussing the development of an enhanced building and occupancy model (ePOE).

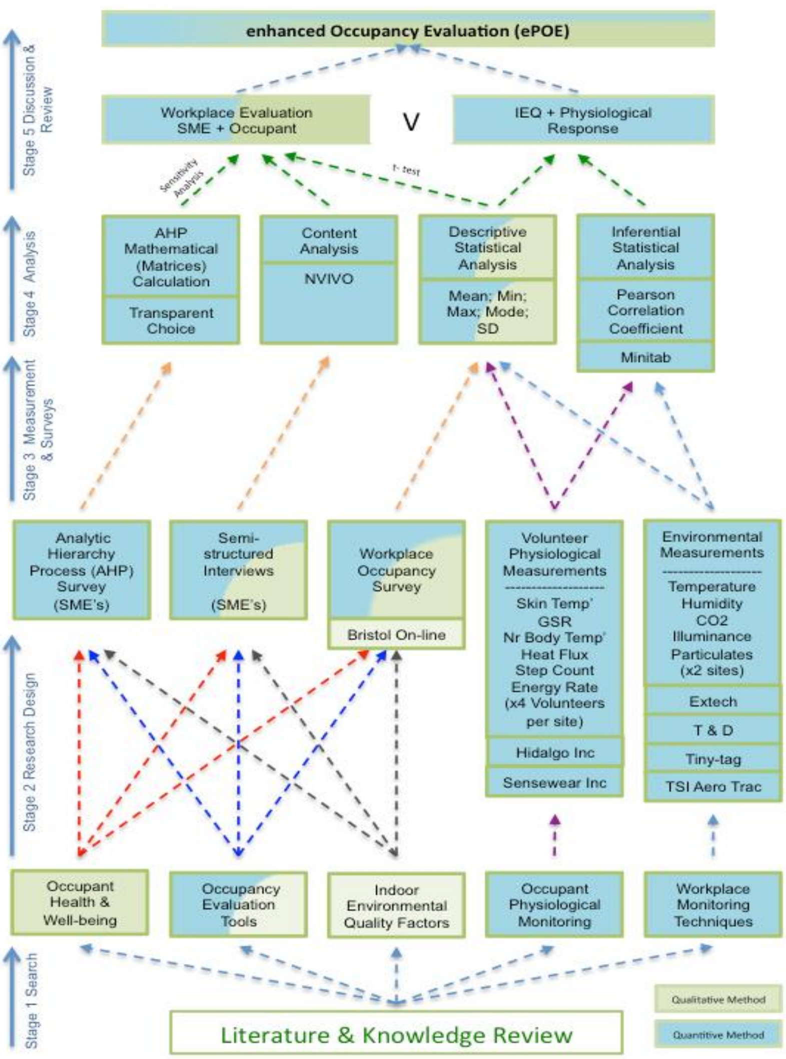


Fig.28 - Research Framework Overview

3.8 Staged Research Model

Allowing data validation and continuous analysis to be undertaken, and to manage the amount of data to be collected, the research was conceptualised into a multi model and staged approach (Fig.28). Five research stages were subsequently developed, then linked together to provide a triangulated view across both the quantitative and qualitative collected data.

3.8.1 Stage 1 - Literature Review

A detailed IEQ literature review was undertaken to understand the research problem and to assess the extent of data required to support the research hypothesis and aim. Also assessed via literature review, were the relevant research methods, data acquisition concepts, data management tools and available technology to simplify the project. A key element of the review was to assess the data to be collected, how to empirically measure and capture the relevant parameters, and how to conduct the project within a live workplace environment. The literature review delivered the following key outputs:

- A clearer understanding of the property industry and its importance to the UK.
- Occupant Health & Well-being as an inclusive current and future concern.
- Available occupancy evaluation tools and their use within this project.
- The extent and inter-connectivity of IEQ factors within the workplace.
- Occupant physiological monitoring as a future innovative building concept.
- IEQ measurement and the lack of effective or sufficient monitoring.
- Potential gaps in knowledge – SME and occupant IEQ expectations

Also resulting from the literature review and based upon the needs of the project, five (5) data collection methods used within the field research were selected.

1. Occupant post occupancy evaluation surveys
2. Analytic Hierarchy Process (AHP) surveys
3. Semi-structured interview questionnaires
4. Workplace environmental monitoring (4 x 1-wk seasonal periods)
5. Occupant physiological performance monitoring (4 x 1-wk seasonal periods)

Focus was applied discretely in each of the above areas in a sequenced approach to manage the large amount of data to be handled.

3.8.2 Stage 2 – Research Design

Comprising of fieldwork and desktop data processing, the research framework provided five (5) discrete work streams for the RE to manage. A sequential data collection method was subsequently developed and adopted to enable a focussed approach to be maintained, particularly across multiple survey techniques and empirical IEQ measurements (Fig.29).

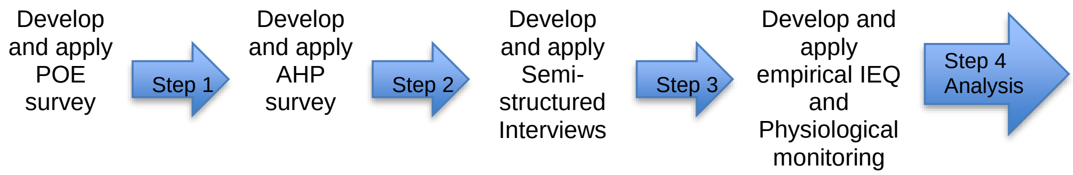


Fig.29 - Sequential Approach to Data Collection

Following the departure of RBS as the original research sponsor, an extensive site search again needed to be conducted at the end of Q4 (year-2) 2014), Fortunately two naturally ventilated research sites were made available to the RE relatively quickly during Q1 2015, and the sequential research approach was applied at both locations. Both sites were occupied by IEQ and building experts allowing the RE to apply the full range of research methods, techniques and tools at each location. Other sites have been utilised (Table 17) however, only two sites, BSRIA and 5 Plus Architects have been used as full research sites.

1. BSRIA - Old Bracknell Lane West, Bracknell, West Berkshire RG12 7AH
2. 5 Plus Architects - 4th Floor, The Hive, 47 Lever Street, Manchester, M1 1FN

Research Sites Utilised					
Location	POE Survey	AHP Survey	Semi-structured Interviews	IEQ Measurements	Physiological Measurements
BSRIA	✓	✓	✓	✓	✓
5 Plus Architects	✓	✓	✓	✓	✓
Ongar Town Council	✓	✗	✗	✗	✗
Brentwood Borough Council	✗	✗	✗	✗	✗
Service Certainty Ltd	✓	✗	✗	✗	✗
University of Reading	✗	✗	✗	✗	✗
Hurley Palmer Flatt	✗	✓	✓	✗	✗
Royal Bank of Scotland	✗	✓	✓	✗	✗
Vertex Ltd	✗	✓	✓	✗	✗

Table 17 - Research Site - Experimental Research Matrix

3.8.2.1 BSRIA Site Description

BSRIA's main UK office (Fig.30) is located at Old Bracknell Lane West, Bracknell, West Berkshire RG12 7AH, United Kingdom (Grid Ref - SU8646890), and comprises of various office, workshop, laboratory and warehouse environments. The buildings are circa 1970's design and have been modernised over the past 45 years to maintain a business focus, however, they have retained the same 1970's façade with no additional thermal; acoustic or glazing treatment. Floors and ceiling are solid cast concrete with all building services being surface mounted unless forming part of the original construction e.g. lighting circuits or heating pipework.

The building façade is single brick outer construction with internal block and plaster finish with single glazed 45% manually operable windows. All windows are provided with horizontal or vertical blinds, with a total wall to window area of approximately 45%. Blinds are manually controlled, with each window having a different blind open/closed setting ranging between 25-100%. The blind adjustment is dependent upon a number of factors; the façade orientation, the internal desk arrangement, and specific occupier preference. BSRIA has no implemented policy concerning the use of window blinds, however, as a result of our research, they are considering such a policy to improve occupant thermal comfort (cooling) during summer periods, and to improve energy efficiency during winter periods by increasing the use of daylight. Artificial lighting is provided by soffit mounted 2x36w (T8) fluorescent prismatic luminaires with zonal manual control, however, we noted a number of failed lamps, and lamps with different colour rendering appearance. Day-lighting as noted from interview responses would appear to be the preferred source of lighting within the open plan office area, with only minimal artificial lighting adopted during the latter part of the day. However as noted, blind settings are in conflict with this preference given the adhoc nature to which they have been adjusted. No supplementary task lighting is provided at any desk positions, suggesting lighting levels are adequate or the occupants have become accustom to the environment.

Using circulated pumped hot water provided through traditional gas fired centralised boilers, the office workspace is heated using perimeter radiators mounted below each window openings There is no mechanical forced air-conditioning or ventilation (Supply/Extract) systems within the office areas, ventilation and cooling is provided naturally via the opening windows set individually by the nearest building occupant. Heating control is achieved using individual thermostatic radiator valves, boiler return temperature control and external temperature optimisation. Spot "comfort cooling" was not present in any office area, therefore, during summer periods the workplace relies upon available natural ventilation and cross air-flows between the different building elevations.

A number of portable desk fans are located throughout the open plan office area, suggesting summer temperatures are uncomfortable in some parts of the office layout. The building orientation is 312º NW a 31º NE aspect with a 55% wall to window aspect ratio. General circulation areas and a central stair core are located within the West façade elevation, with all office areas extending along the North East elevation. Floor to exposed concrete soffit height is 2.8m and the research area comprises of 21.6m x 8m (Fig.30).

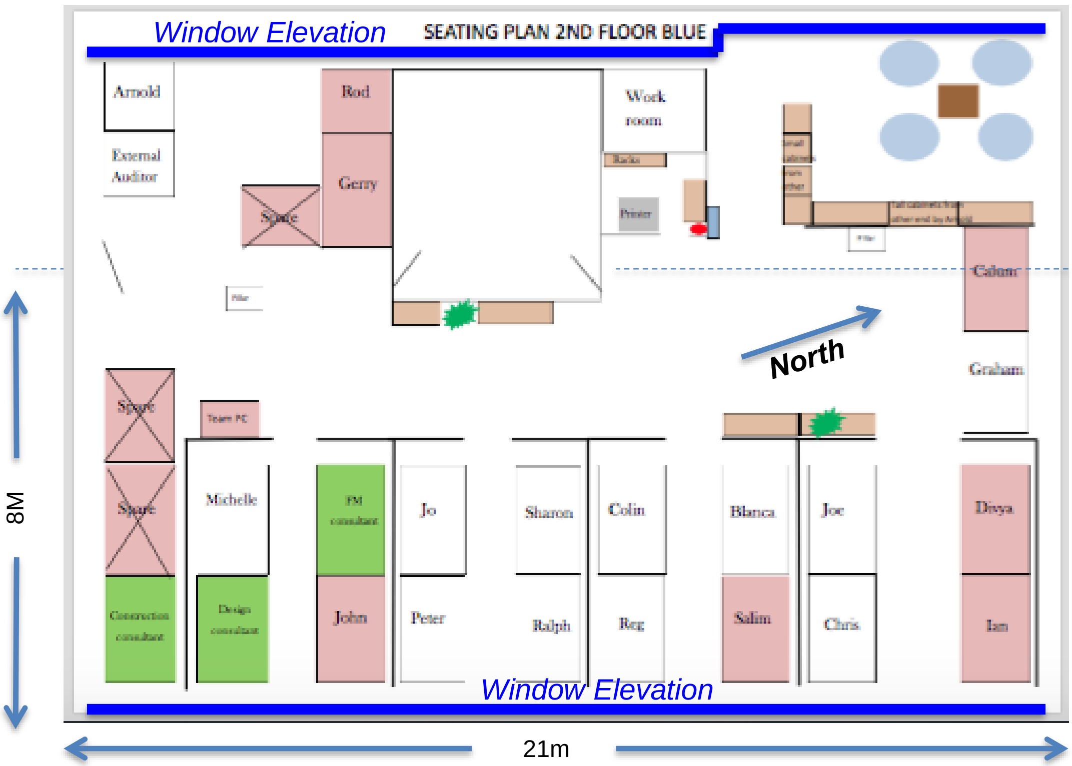


Fig.30 - BSRIA Office Layout – Level 2 Blue Building – Bracknell (UK)

The office workplace comprises of dark blue carpeted floor tiles, light beech effect desktops, cream colour walls and green/blue desktop privacy panels to a height of 1.4m above finish floor level. Significant amounts of ICT equipment are installed at each desk location, including P.C's, laptops and IP telephony. There is no centralised building management system (BMS) or controls installed. Various large pot plants are distributed throughout the workplace, and walls are plain with no stimulating features accept for whiteboards and message boards. Desks are positioned in rows at right angles to the NE façade and configured into four square cellular arrangements as noted within Fig.30.

The space is designed for occupancy of 20 full time employees (FTE) on an adhoc basis due to work requirements, however, a measured weekly average occupancy level of 10_{FTE} was recorded during our 5-day assessment periods. This equates to a designed occupancy density ratio (*dodr*) of 1_{FTE} per $7m^2$ or an actual weekly average density of 1_{FTE} per $12.6m^2$.

$$\frac{21.6m\ x\ 8m}{20} = 1_{FTE}: 8.4m^2 \ldots\ldots\ldots\ldots designed\ occupnacy\ ratio \ldots\ldots\ldots equation\ 1$$

$$\frac{21.6m\ x\ 6m}{10} = 1_{FTE}: 17.3m^2 \ldots\ldots\ldots\ldots measured\ occupancy\ ratio \ldots\ldots equation\ 2$$

The area is configured as follows:

Total floor area:	*21.60m x 8.00m*	*= 172.80m²*
Total Volume:	*21.60m x 8.00m x 2.80m*	*= 483.80m³*

When seated each occupant "physically" occupies (including desk/pedestal space) $3.40m^2$, which includes a proportion of unusable space due to desk layout and filing requirements.

3.8.2.2 5 Plus Architects Site Description

The main office of 5plus Architects is located on the 4th floor, The Hive, 47 Lever St., Manchester M1 1FN, United Kingdom (Grid Ref - SJ846985.) and is a recently constructed multi use building. The space is fully open plan and is used by 5plus Architects as their northern practice design studio. The building is of 2010 construction and is specifically designed (Arup) to a naturally ventilated (NV) mode of operation.

The building was constructed to 2010 UK building regulations and the latest BS EN standards with a number of environmental enhancements (Fig.32). The space is designed upon a 7.5m x 6.0m grid with a central service core comprising of lifts, toilets and main staircase, the fit out space forms from the central core creating reception, office, photocopy, IT and meeting rooms. (Fig.31).

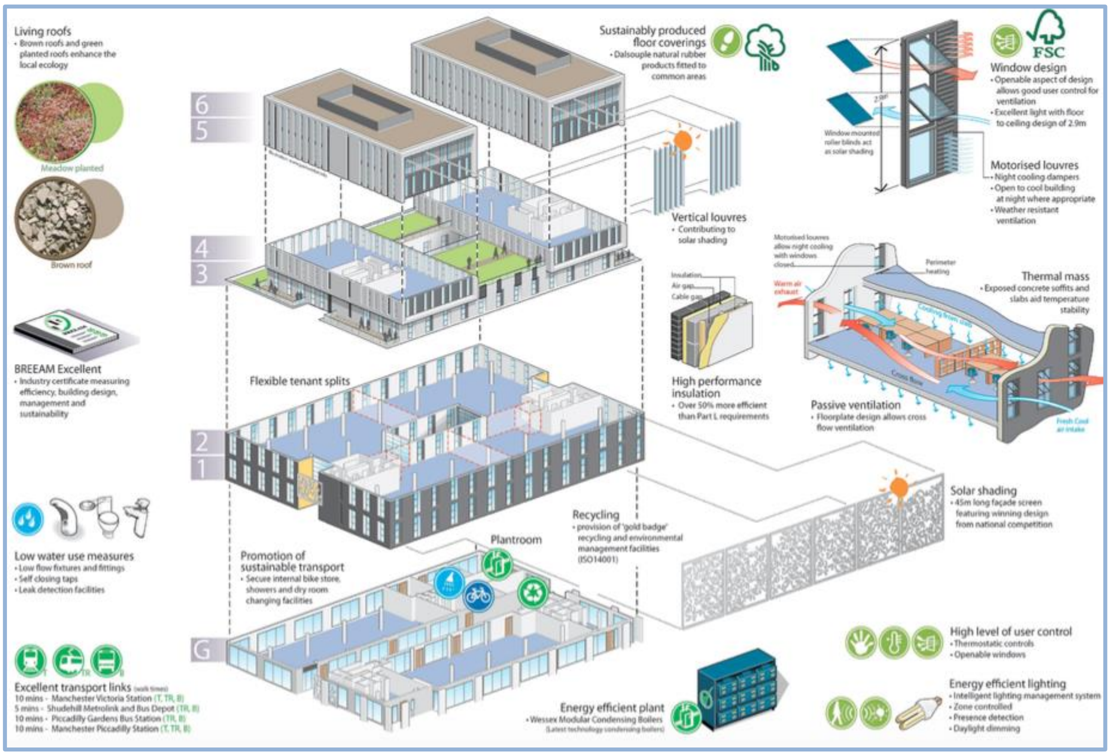


Fig. 31 – 5plus Architects Building Design & Research Environment

The building façade is single brick outer construction with internal block and plaster finish with double glazed (35%) manually operable windows within each window section. All windows are provided with horizontal blinds, with a total wall to window area of approximately 55%. Blinds are manually controlled and each window has a different setting from either 25-100% closed depending upon the windows orientation within the façade and internal desk arrangement. Staff are encouraged to maximise available daylight by keeping the blinds 100% open, but are able to adjust to avoid external glare and to reduce thermal gains. Windows are both manually and mechanically operable via window handle, wall switch and motor activator. The windows open to approximately 20% free area. Artificial lighting is provided by soffit suspended 1x36w (T5) fluorescent luminaires and occasional decorative spot lamps. Lighting control is provided via dimmable and zonal manual control with automatic time scheduling out of normal core hours. Day-lighting is the preferred source of illumination within the open plan office area, however, the artificial lighting is used extensively due to the design of the façade and the shading affected created by the perimeter wall panels. There is no supplementary task lighting on any desk positions.

Perimeter trench radiators provide heating using traditional gas fired centralised boilers, with no mechanical supply or extract ventilation provided. Heating control is internally managed using individual thermostatic radiator valves, wall mounted sensors, boiler return temperature control and external temperature optimisation.

The building orientation is 306^{o} NW, with a 32^{o} NE aspect containing 55% window to wall aspect ratio of 45%. A central stair-core and general circulation areas are located within the West façade elevation with all areas extending along the North East elevation. Floor to exposed soffit height is 3.2m and the research area comprises of 15m x 10.5m of open plan office area.

The office workplace comprises of dark grey-carpeted floor tiles, grey desktops, concrete/plywood walls and exposed grey concrete soffit. Significant amounts of ICT equipment is installed at each desk location including P.C's, laptops and telephony. There is no BMS installed within the space, however, a basic interface exists between the main fresh air dampers located upon opposing perimeter walls and the landlords BMS system.

The occupied office space and research area comprises of 15.0 x 10.5m and has a floor to concrete soffit height of 3.2m. Occupants are positioned in groups of 8-12 modular desk rows and orientated parallel to the NE façade (Fig.32). The space is occupied by 36 full time employees (FTE) on an adhoc basis due to work requirements, with a measured weekly average occupancy level of 28_{FTE}. The designed occupancy density ratio (*dodr*) of 36_{FTE} equates to 1_{FTE} per $4.37m^2$ with an actual weekly average density of 1_{FTE} per $5.62m^2$:

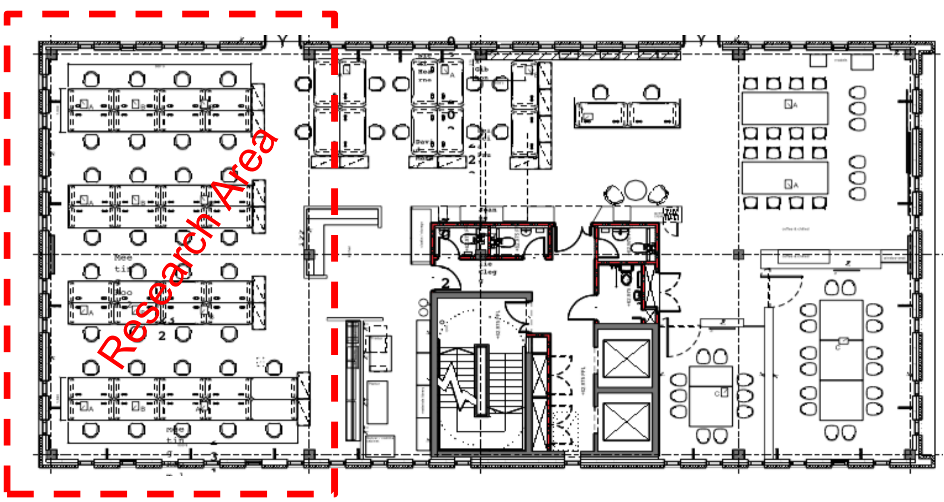


Fig.32 - 5 Plus Architects Workplace Layout – Manchester (UK)

$$\frac{15.0m \ x \ 10.5m}{36} = 1_{FTE} : \ 4.37m^2 \ldots\ldots\ldots\ldots designed \ occupnacy \ ratio \ldots\ldots equation \ 3$$

$$\frac{15.0m \ x \ 10.5m}{28} = 1_{FTE} : \ 5.62m^2 \ldots\ldots\ldots\ldots measured \ occupancy \ ratio \ldots\ldots equation \ 4$$

The area is configured as follows:

Total floor area: *15.0 x 10.5m* *= 157.5m²*

Total Volume: *15.0 x 10.5m x 3.2m* *= 504.0m³*

Seated each occupant "physically" occupies (inc. desk/pedestal space) 3.40m², which includes a proportion of unusable space due to desk layout and filing requirements.

3.8.2.3 Research Site Summary

Although both sites were constructed 40yrs apart, the overall principles governing the IEQ factors have generally remained the same. The methods of lighting, cooling and heating the workplace are of equivalent principles although applied differently in the case of 5 Plus architects as a consequence of their active cross flow wall mounted ventilation dampers. Both workplaces provide an office type environment for static desktop ICT work tasks, the use of break-out spaces and quiet areas is again provided, but again applied differently due to the layout and desk arrangements. Although the research areas are of similar dimensional layout, the actual occupational densities are a result of the work intensity and work tasks being undertaken. Table 18 summarises the research site key dimensional characteristics.

Location	Dimensions			Area (m²)	Vol (m²)	FTE (t)	FTE/m² (d)	FTE/m² (m)	FTE/m² (o)
	L (m)	*W (m)*	*H (m)*						
5 Plus	15.0	10.5	3.2	157.5	504	36	4.37	5.62	3.40
BSRIA	21.6	8.0	2.8	172.8	483	20	8.64	17.2	3.40

(t) – total; (d) – design; (m) – measured; (o) - occupied

Table 18 - Research Site Key Characteristic Comparison

Having assessed the sites for suitability for use within a comparative and sequential research model, the following methods and techniques were deployed at each research site

1. Occupant post occupancy evaluation surveys
2. Analytic Hierarchy Process (AHP) surveys
3. Semi-structured interview questionnaires
4. Workplace environmental monitoring
5. Occupant physiological performance monitoring

Due to initial issues with data quality, reliability and comprehension of the written survey requirements, the delivery of each method was managed directly by the RE who attended each site on a weekly basis Mon-Fri - 09:00 - 17:00.

3.8.2.4 Occupant Post Occupancy Evaluation Surveys

Building users (occupants) are people with specific interest in the building, these include staff, managers, customers or clients, visitors, owners, designers or maintenance teams, all of whom can be said to be human functionary sensors providing both quantitative and qualitative data feedback from their physical and psychological experiences.

Post Occupancy Evaluation differs significantly from conventional surveys and market research. It uses the direct, unmediated experiences of building users as the basis for evaluating how a building works for its intended use, and provides an indication as to its performance and productive affect to the users.

From the perspective of the people who use them, post occupancy evaluation (POE) surveys involve the systematic evaluation of opinion about buildings in use. They assesses how well buildings meet occupier and user needs, identify ways to improve building design & operation, determine performance levels and assess general fitness for purpose. POE can be classified and defined as an assessment method, an analysis tool or as an investigative framework to assess building performance. POE can be further categorised into delivering the following key aspects:-

1. Quantifies occupant satisfaction
2. Determines value for investment
3. Provides insight for Facility Managers (FM's)
4. Engages with building occupants
5. Assesses building performance
6. Highlights areas of concern
7. Benchmarks performance

This research focuses upon the aspect of building performance and engages with the building occupants to assess the physiological impacts of the workplace real time.

3.8.2.5 POE Survey Techniques

There are many different survey types applied across many different requirements, however, they are all supported by three main yet general techniques:-

1. ***Cross-sectional*** surveys – these surveys use a selected sample drawn from a section or segment of the area to be studied. This approach is a time relative survey as it is conducted only once so cannot lead to predictive assessments. The benefits of this approach however, is that it is simple, expedient and easily managed with the participants.

2. ***Successive Independent*** surveys use multiple random samples taken from the area to be studied at one or more times during a period. This approach provides an indicative view of the survey population, but cannot identify specific causes or changes due to the random nature of the sample selection. The benefits of this approach however, is that it is a random sampling technique, so does not burden the same participants particularly when large populations are to be surveyed.

3. ***Longitudinal*** surveys take a measure of the same sample at multiple set time points, enabling measures to be consistently compared and for causes to be referenced. The benefits of this approach, is its ability to allocate causes to specific issues based over time, however, it can burden participants whom may not complete the survey over the full period of time. Managing such studies can be a significant problem.

The specific POE survey developed within this research is a consequence of the in-field nature of the evaluation, the unique type of naturally ventilated workplace being investigated and the need to adopt minimal intrusion to the occupants. A ***cross-sectional*** survey method has therefore been adopted.

The use of a subjective POE survey response technique is only one part of the survey process. Once the responses are collected, we use descriptive statistical analysis to translate the responses into a quantitative output that is then analysed and compared between the two research sites.

3.8.2.6 POE Survey Template

Having prioritised the data collection methods (1-5 above), the first task to be performed was the development of a POE survey template. The various existing POE survey templates referred within Chapter 2, were not considered appropriate for this analysis, either in terms of their type e.g. benchmarking, or were too specific to an area of particular interest. Given our own specific desire to focus upon NV IEQ factors and occupant workplace responses, a bespoke POE template was considered more appropriate.

A number of initial templates were produced ranging from 10 – 50 questions, however, the primary concern within the design of the survey template was to keep the questions to as few as possible while maintaining a credible level of response. It was also important to minimise the time required to undertake the survey when working within a live workplace environment. Seven re-iterations of the template were required before a final survey template was agreed.

Survey trials (5) were conducted within the Property Services department of the Royal Bank of Scotland to assess for potential issues, and a number of conflicts were noted and subsequently addressed (Table 19).

Initial POE Template Issues	
Issue	**Mitigation**
Questions were not clearly understood	*Questions were re-structured relevant to the required answer and formats changed to link the question to the answer format more discretely.*
Some questions were too long	*Questions were shortened to be more explicit.*
Too many questions overall – Time taken to complete the survey too long.	*Questions were consolidated were possible and a time limit of 10-mins applied.*
Similar questions	*Requirements combined into an explicit format.*
Paper based survey was not environmentally astute and difficult to manage	*An electronic e-mailed survey produced, assisting with shortening the time to complete.*

Table 19 - POE Survey Response Issues v Mitigation

Developed using the *"Bristol On-line Survey (BOS)"* tool, the final Occupant POE survey template is provided within Appendix A. The BOS tool was selected in lieu of other proprietary internet based systems, as the system is located on a secure university hosted server and not an internet based server. Each survey was issued from the BOS system using a site bespoke e-mail www link, and set with a 4-week time-out period.

3.8.2.7 POE Sample Size

When designing or considering a POE survey sample size, the researcher needs an understanding of the statistics that drive the sample size decisions. Within research there are two main types of sampling method (Dawson 2009) each having their own set of specific techniques (Table 20).

1. Probability samples – large subject managed through probability analysis
2. Purposive samples – focused investigative experimental research

Sample Types	
Probability Sample Techniques	Purposive Sample Techniques
Random sampling – selecting a sample from a large accurate holistic database.	***Quota sampling*** – selection of a specified number of groups to be represented.
Cluster sampling – a sample selected at random within a given area of interest.	***Snowball sampling*** – engaging with respondents and seeking their input into who to select next for interview.
Systematic sampling – selection of a random point within a given data set, then every say 3rd persons selected.	***Theoretical sampling*** – emerging data and theory informs the sample size requirements and target area.
Stratified sampling – subject areas categorized from which a random sample is obtained.	***Convenience sampling*** – generally due to limited time or budget, therefore familiar target areas and/or data are selected.
Areas for concern: Sample bias; structure; cluster selection error; recommendation bias; accuracy of existing data; inappropriate grouping.	

Table 20 - General Sample Types and Techniques

A "purposive" theoretical sampling approach (Dawson 2009) was utilised to deliver both the occupant POE, AHP SME surveys, and the SME semi-structured interviews. Existing and emerging theory led to the adoption of this approach, as it focused the RE towards investigating both the research sites, expanding the sample requirement to other sites were the occupant POE, SME semi-structured interview and SME AHP were also delivered.

The occupant POE sample size was calculated using the following statistical requirements:

1. ***Margin of Error (Confidence Interval)*** — No sample is perfect, therefore it is important to allocate an acceptable allowance for error. The confidence interval determines how much higher or lower than the surveyed mean you are willing to let your sample mean fall. A margin of error of +/- 5% is

generally acceptable.

2. ***Confidence Level*** — defines how confident you want the results to be to allow the actual mean to fall within the set confidence interval (+/-5%). The most common confidence intervals are set at 90%, 95% or 99% confident level.
3. ***Standard of Deviation*** — determines how much variance you expect in your responses. In calculating this sample size, the general decision uses a factor of 0.5, as this is the most forgiving number, and ensures that the sample will be large enough to be effective.

Calculating the sample size, the confidence level corresponds to a defined ***Z-score***. This is a constant value needed for the statistical calculation [eq. 5].

The z-scores for the most common confidence levels are calculated as follows:

90% Z Score = 1.645; 95% Z Score = 1.960 99% Z Score = 2.576

Therefore under our research the following sample size was calculated as follows:

$$Sample\ size = \frac{Zscore^2\ x\ SD^2\ x\ (1-SD^2)}{CI^2}$$ ....[eq. 6]

$$Sample\ size = \frac{1.96^2\ x\ 0.5\ x\ (0.5)}{0.05^2}$$

$$Sample\ size = \frac{3.8416\ x\ 0.25}{0.0025}$$ = 384.16 ≠ **385 (respondents needed)**

Surveys were issued as detailed within Table 21

Deployed Surveys – Naturally Ventilated Buildings			
Organisation	Location	Potential No. of Responders	Actual No. of Responders
BSRIA	Bracknell	75	X
5 Plus Architects	Manchester	55	X
Ongar Town Council	Brentwood	12	X
Brentwood Borough Council	Brentwood	60	X
Service Certainty Ltd	Brentwood	10	X
University of Reading	Reading	50	X
Vertex Ltd	Loughton	12	10
Total		264	X

Table 21 - Deployed POE Survey Locations

3.8.2.8 Semi-structured Interview Surveys

Semi-structured interviews were seen as an ideal solution to assess subject matter expert appreciation of IEQ factor importance. Coached by a pre-defined set of questions based upon previous experience gained by the RE and a literature review, the use of a semi-structured interview technique facilitated an ability to use an open question format to stimulate expert responses.

There are advantages and disadvantages in adopting such a technique, and Table 22 indicates the key advantages and disadvantages (Robson 2002).

Semi-structured Interview Technique	
Advantages	**Disadvantages**
Allows for flexibility during the interview	Possibility of loss of control by the researcher
Ability to clarify misinterpretation	Expert v Researcher understanding could be questioned
Tests the participants knowledge	Researcher needs to be of equivalent knowledge
Encourages rapport and discussion	Open ended questions difficult to review
Opinions can be aired and discussed	Opinions are subjective and not quantifiable
Possible new angles of discussion achieved	Time consuming – Interviewing & transcribing.

Table 22 - Semi-structured interview Issues

The SME semi-structured interview questions were formulated to question if any relationship existed between the occupant POE survey and the SME Analytic Hierarchy Process survey responses. The development of the interview survey questionnaire again required the questions to be minimised to the lowest number possible, therefore, the questions all though open ended, necessitated more than one question to be incorporated within each question. Combining multiple questions into a single question format was at first thought not to be an appropriate method, however, this format actually stimulated the discussion introducing a significant debate between the researcher and the survey volunteer. The final interview questionnaire is provided with Chapter 4.

3.8.2.9 Semi-structured Interview Sampling Size

Sampling size was not to be an exact science, as no statistical calculation method existed to determine an actual sample size. In absence of any method two solutions were adopted.

1. A percentage of occupant POE responses was calculated = 385 x 10% = **38**
2. Sampling was selected from across key industry stakeholders.

Selection of interview volunteers was based upon approaching various stakeholders and briefing them in terms of the research project, expected outcomes and the specific need to interview building subject matter experts. The criteria for volunteer selection was presented (Table 23), then within each organisation an invitation e-mail was issued seeking volunteers.

Subject Matter Expert Interview Criteria	
Criteria	Requirement
Age	>35-yrs
Gender	Female or Male
Experience	>15-yrs – last 5-rs within the built environment
Skills	M&E; Sustainability; FM; Construction; Design
Qualifications	Undergraduate; Masters
Position within Organisation	Senior, Director, Partner

Table 23 - SME Research Volunteer Criteria Assessment Matrix

3.8.2.10 Semi-structured Interview Questionnaire Design

The design of the semi-structured questionnaire targeted the same areas included within the POE survey. The intent of aligning the questionnaire in this way, was to understand if gaps existed in terms of what experts believe are important to them, and to what occupants experience as important to their own performance. A total of 10 questions formed the questionnaire and are detailed within Chapter 4. The semi-structured questionnaire was administered to the same SME's as the AHP survey, therefore the ability to connect responses between the AHP and questionnaire was considered acceptable.

Each organisation participating in the survey, requested that the interview should not exceed 45-mins and that the time the volunteer should be away from their desk be

<60-mins. Trial interviews were conducted by the RE at the Royal Bank of Scotland, and amendments to the style of the interviewer and content were undertaken.

Prior to each interview, the RE contacted each of the volunteers to confirm meeting venue, date & time of the interview. The questionnaire was not presented to the volunteer in advance of the interview, however, an explanatory note concerning the research and details of the interview structure were provided (Appendix E). The interview was conducted by the RE asking each question in sequence and coaching the volunteer to respond in a managed time period of 3-4 minutes. Interview times ranged from 35-50minutes.

The use of real time transcription was trialled and rejected as it was simply taking too much time to complete during the trial. It also prevented the opportunity to encourage further discussion on points that were or might be uncovered. To resolve this issue the RE used the memo recoding facility on his iPhone recording each interview for later transcription. The ability to discretely prompt the discussion was found to be a very positive feature of the amended interview technique.

3.8.2.11 Semi-structured Interview - Analysis Methods

The analysis of semi-structured interviews can be considered to be a qualitative method of analysis as it yields no numerical data. Four methods were reviewed to determine an appropriate analysis method.

1. *Thematic analysis* - data is analysed by a common theme, which is highly inductive i.e. themes emerge from the data and are not imposed in any way by the researcher. Data collection and analsysis occur simultaneously using this method, however, care needs to be taken using this method, as it could distort subsequent results as a consequence of the semi-structured nature of the interview.
2. *Comparative analysis* - similar to thematic analysis and sometimes used together, the researcher uses a comparison technique to compare and contrast data between each transcript until a clear understanding of the data is presented. Using a scalar representation, this method seeks to place each response on a scale of association with the questions, allowing further questioning or surveys to be developed if necessary.
3. *Content analysis* - the analysis occurs when all the data is obtained, which makes this method more mechanical in nature. The researcher systematically

reviews each transcript and applies a set of pre-defined categories and codes to specific words and phrases as they appear. Other issues and responses may also be discovered and these can be added to the categories and/or coding structure. Particularly useful for analysing open ended questions.

4. *Discourse analysis* – This methods looks at patterns of speech usually within groups with much of the analysis seem as intuitive and reflective i.e. how people respond to questions, or the way in which engage in the conversation.

Due to the SME nature of the interviews, questionnaire design, and the option to code and categorise responses, a *Content analysis* method was selected. To assist in the coding and presentation of the data, the NVIVO software package was adopted.

3.8.2.12 Analytic Hierarchy Process (AHP) Method

Our research hypotheses proposes that a gap exists between what building occupants expect their workplaces to deliver, and in what building owners, designers and operators believe occupants actually need. The AHP process (Saaty 1980 & 2000) is a proven technique for assessing hierarchical decision-making when faced with many inter-related factors or choices. In our use of the AHP process, we use the

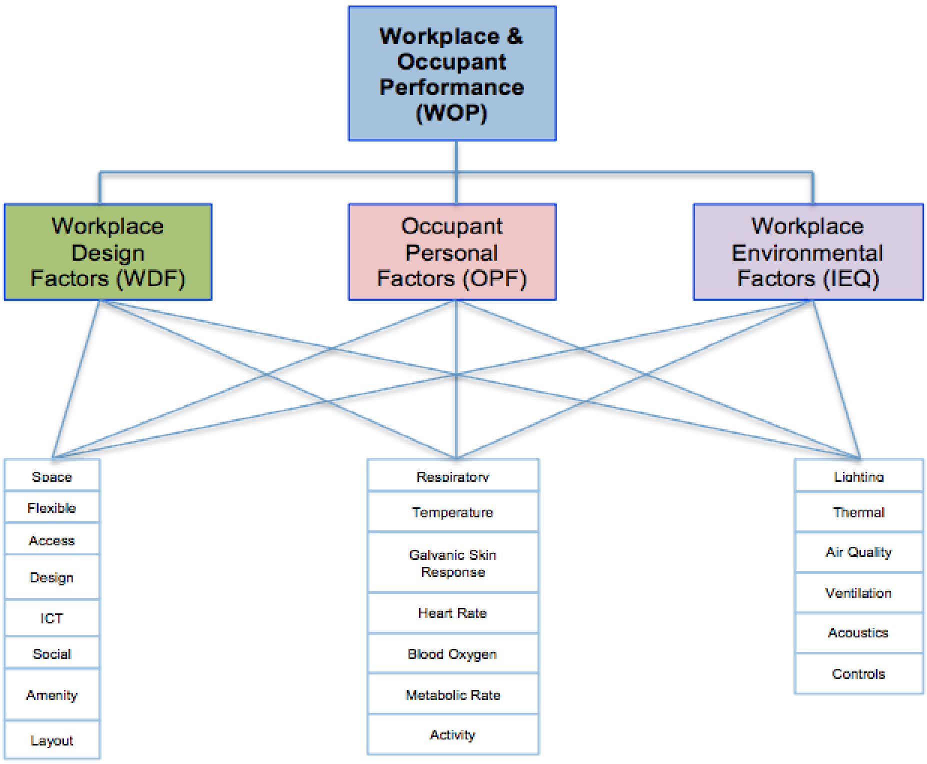


Fig.33 – AHP Process Model – (part model due to scale – see Appendix…for full model)

pair-wise comparison technique developed by Saaty, to prioritise known ordinal factors, as a result of the relative importance assigned by the SME's to each cardinal factor. The inter-related ordinal and cardinal factors detailed previously within Fig.33 are the basis for the AHP model.

Criteria ranking is obtained using a 9-point scaled questionnaire delivered as a paper survey during the SME semi-structured interview. The completion of each questionnaire facilitates a pair-wise "relative importance" calculation to be conducted ranking each factor in importance to each other. A sample question format is detailed below with the full questionnaire provided within Appendix F. A total of 109 questions were ranked within the questionnaire.

Q1 – "***Within the modern workplace how would you personally rank the importance of the building's HVAC system to recognise my presence and adjust to my pre-set personalised preferred thermal environment?"***

Not at all Important	Moderately Important			Important	Very Important			Extremely Important
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
			✓					

Table 24 – Pair –wise Ranking Scale & Survey Response Chart

Forming the pair wise priorities, ranking of the priorities is completed to obtain an Eigen factor which is derived from mathematically calculating 1st and 2nd order matrices. Once the pair wise relative importance calculation has been assessed within the pair-wise matrix, a 1st order matrices value A^1 is calculated. Having calculated A^1, a 2nd order matrices value is calculated by squaring the 1st order values – $A^1 \times A^1 = A^2$ ***[Eq. 7]*** Adding the rows across the matrices we sum to a total value, then "normalise" the A^2 row sums, by dividing each <u>row total</u> by the <u>summated total value</u>. The individual row normalised values should add to 1.0 at all times if the calculation is to be correct. These normalised values are referenced to value E_0 i.e. the Eigen Value.

Example response AHP process equation:

<u>1st order Matrices</u> **<u>2nd order Matrices</u>**

$$A_1 = \begin{bmatrix} 1.00 & 0.50 & 3.00 \\ 2.00 & 1.00 & 4.00 \\ 0.33 & 0.25 & 1.00 \end{bmatrix} \longrightarrow (A_1)^2 = A_2 = \begin{bmatrix} 3.00 & 1.75 & 8.00 \\ 5.33 & 3.00 & 14.00 \\ 1.17 & 0.67 & 3.00 \end{bmatrix} \ldots\ldots\ldots\ldots \textbf{[Eq. 8]}$$

$$\Sigma \text{ Rows } A_2 = \begin{matrix} 12.75 \\ 22.23 \\ 4.84 \\ \hline \end{matrix} = (E_0) = \frac{\Sigma \text{ Rows A2}}{39.82} = \begin{matrix} 0.3202 \\ 0.5583 \\ 0.1215 \\ \hline \end{matrix} \quad \text{...............} \textbf{\textit{[Eq. 9]}}$$

$$total\,\Sigma \quad 39.82 \qquad\qquad total\,\Sigma \quad 1.0000$$

The matrices undergo a further iteration of the process to obtain a 3rd order of matrices values by squaring the 2nd order values = A^2 x A^2 = A^3 ***[Eq.3].*** Again, we add the rows across the matrices and sum to a total value, we then "Normalise" the A^3 row sums, by dividing each <u>row total</u> by the <u>total value</u>. This will then be the individual row normalised values, which should add to 1.0 at all times. We annunciate this value as E_1 - (Eigen value) ***[Eq.4]***

<u>3rd order Matrices</u>

$$A_3 = (A_2)^2 = \begin{bmatrix} 27.67 & 15.83 & 72.50 \\ 48.33 & 27.67 & 126.67 \\ 10.56 & 6.04 & 27.67 \end{bmatrix} \text{...} \textbf{\textit{[E.10]}}$$

$$\Sigma \text{ Rows } A_2 = \begin{matrix} 116.00 \\ 202.67 \\ 44.27 \\ \hline \end{matrix} = (E_1) = \frac{\Sigma \text{ Rows A2}}{362.94} = \begin{matrix} 0.3196 \\ 0.5584 \\ 0.1220 \\ \hline \end{matrix} \quad \text{...........} \textbf{\textit{[Eq.11]}}$$

$$total\,\Sigma \quad 362.94 \qquad\qquad total\,\Sigma \quad 1.0000$$

The next step in the AHP iteration process is to determine the difference between the 2-sets of Eigen Values by subtracting E_1 from E_0 = (E_1 - E_0) **-** If this value is Zero or <0.1 – STOP the process, or continue with further A^n matrix iterations.

$$E_1 - E_0 = \begin{matrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{matrix} - \begin{matrix} 0.3202 \\ 0.5583 \\ 0.1215 \end{matrix} = \begin{matrix} -0.00058 \\ 0.00015 \\ 0.00043 \\ \hline \end{matrix} \quad \text{.................................} \textbf{\textit{[Eq.12]}}$$

$$total\,\Sigma \quad 0.00000$$

Using Saaty's Consistency Ratio (CR) table, these final Eigen values or ranking of priority values, are the added to the model. The consistency ratio, or ratio to confirm response accuracy across many response, is utilised to determine how consistent the judgements represent SME responses, which are then relative to large samples of random judgements, particularly when undertaken across multiple survey responses. If the calculated CR value is >0.1for example, then the judgements or responses should be deemed to be random and the exercise is valueless and needs to be repeated.

When calculating the CR, the 1st order Eigen values are utilised and a further matrices developed A_x. The 1st order matrix is subsequently multiplied by its 3rd order Eigen value [E1} creating its own matrices with the symbol (λ_{max}). Once the value of (λ_{max}) is obtained, it is averaged in respect of the normalised Eigen values.

$$\underset{[A1]}{\begin{bmatrix} 1.00 & 0.50 & 3.00 \\ 2.00 & 1.00 & 4.00 \\ 0.33 & 0.25 & 1.00 \end{bmatrix}} \times \underset{[E1]}{\begin{bmatrix} 0.3196 \\ 0.5584 \\ 0.1220 \end{bmatrix}} = \underset{[\lambda_{max}]}{\begin{bmatrix} 0.9648 \\ 1.6856 \\ 0.3680 \end{bmatrix}} \quad \text{...} \textbf{\textit{[Eq13.]}}$$

$$\lambda\,(\max) = \begin{matrix} 0.9648 & / & 0.3196 & & 3.018660 \\ 1.6856 & / & 0.5584 & & 3.018561 \\ 0.3680 & / & 0.1220 & & \underline{3.016985} \\ & & & total_{(mean)} & 3.018068 \end{matrix} \quad \text{....................................} \textbf{\textit{[Eq.14]}}$$

Having obtained (λ_{max}) - the Consistency Index (CI) value is now calculated;

CI = (λ_{max}-n)/(n-1) ***where n= the number of criteria assessed*****……………………………...........[Eq.15]**

CI = (3.0108-3)/(3-1) =0.009**………………………...[Eq.16]**

The final step within the AHP process, is to calculate the Consistency Ratio using Table-1 below. The upper row is the number or order of the random matrix, and the lower is the corresponding index of consistency for random judgments. The final CR is therefore calculated as follows:.

CR = CI/0.58 = 0.0090/0.58 = 0.01552**……………………….........................[Eq.17]**

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

Table 25 – Saaty's Consistency Ratio Table (1-15)

A Consistency Ratio <0.1 (10%) confirms the evaluations are consistent.

Due to the extent of the project data collection and management required, it was decided to create a multi-criteria AHP decision making software tool to expedite the processing of results.

3.8.2.13 Environmental Measuring Pole (EMP) & Devices

Within each research location at BSRIA & 5 Plus Architects, four monitoring poles were designed, constructed and installed. The design of the pole reflects the environmental data collection parameters described within ASHARE Guide 55, and was developed to simplify site installation within two very busy workplaces.

The location of each pole was determined locally within each office, and fitted to each desk using either clamps, cable ties or steel bolts. The poles were installed out of hours on the Friday evening prior to the weekly monitoring period enabling the monitoring to commence from start of business Monday and through to just before close of business on the Friday (5-days). A relatively early finish on the Friday was to allow for the poles to be removed prior to the offices being closed for the weekend.

Each pole (Fig.34) comprised of a 1900mm x 38mm x 19mm galvanised unistrut channel to which the selected measuring & recording devices were fitted. A white plastic cover was fitted to the channel to secure the interconnecting cabling between the devices and their respective sensors and to provide an acceptable finish.

The location of each pole was determined by the desk location of the research volunteer and was secured as close to the Sensewear armband wearing volunteer as possible. Adjacency of the sensors to the volunteer in some instances necessitated the relocation of the desk pedestal, but this was crucial to obtaining IEQ measurements relative to where the

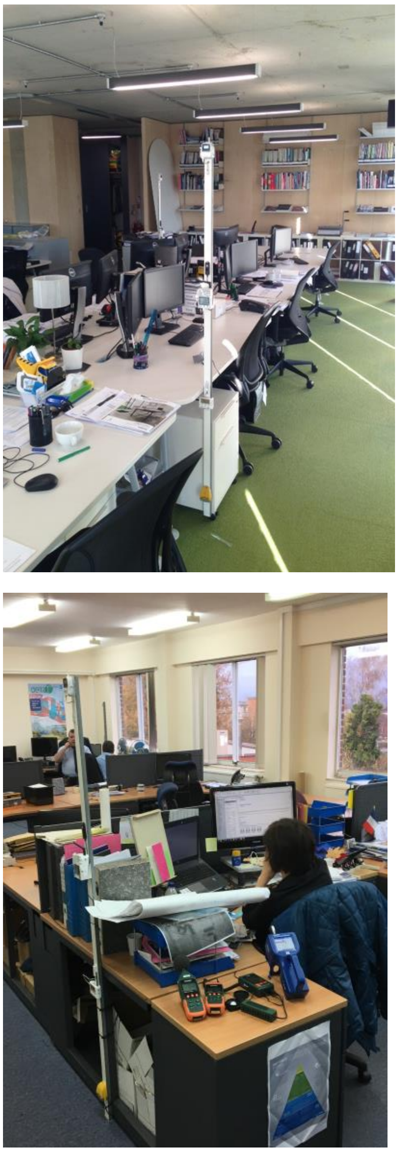


Fig.34 Environmental Monitoring Pole Location - 5Plus Architects (above); BSRIA (below)

volunteer was located within the space. It was also crucial that we did not hinder the volunteer in any way or cause any annoyance.

The requirement to have minimal intrusion and disruption within the working environment resulted in the selection of a wireless solution for the EMP monitoring devices. Of the four measuring devices fitted to each EMP's, three were wireless units, however, the fourth device was deployed as a standard Tiny-tag temperature and humidity sensor due to its location in case it was damaged and needed to be replaced. Fig.35 indicates the location of the EMP's and background IEQ monitoring equipment at BSRIA.

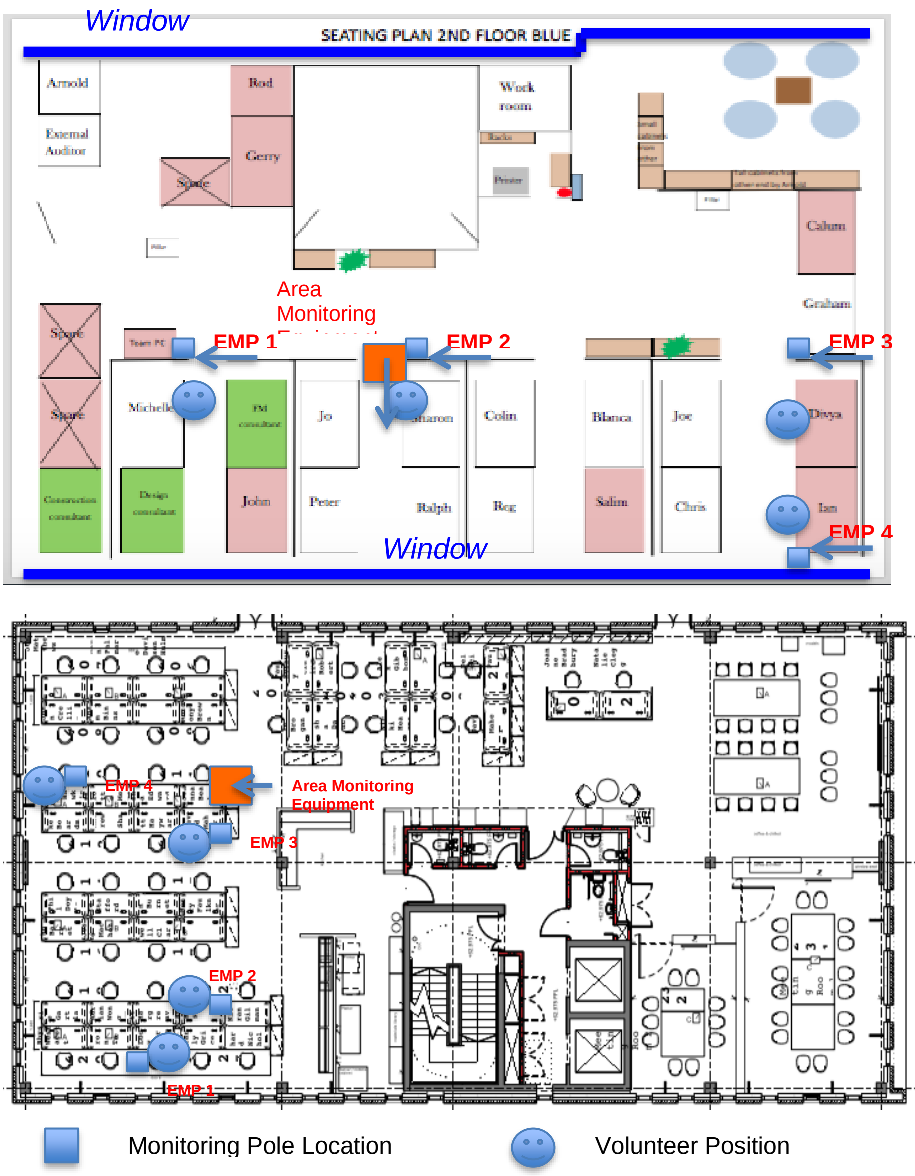


Fig.35 Location of EMP & Area Monitoring Devices – BSRIA (above) – 5Plus Architects (below)

All units were battery powered for the duration of the 5-day monitoring period this avoided some of the health & safety issues resulting from the health & safety risk assessment. However, due to the set data interval being set at 2-mins and the overall power consumption of the unit during trials, it was discovered that the T&D temperature, humidity and CO_2 sensor was unable to monitor passed 48hrs. This unit was subsequently powered using a 230v/6v a.c/d.c power adaptor supplied by the OEM. All measuring devices were set to a 2-minute data recording intervals.

Each 1.9m Monitoring pole was fitted with 4 separate monitoring devices aggregating to 16 separate devices deployed at each site, with each pole measuring the following IEQ parameters. Individual devices were referenced to each pole (Table 26).

Environmental Measuring Pole (EMP) Configuration		
Pole Reference	**Unit References**	**Measured Parameter**
EMP 1	Units 1: 5; 9; 13	• Temperature/Humidity • Illuminance (vertical) • CO_2
EMP 2	Units 2; 6; 10; 14	
EMP 3	Units 3; 7; 11; 15	
EMP 4	Units 4; 8; 12; 16	

Table 26 - Environmental Measuring Pole – Individual IEQ Monitoring Unit Configuration

Table 27 indicates the frequency of the site visits and the measurements collected. Where is indicated, these measurements were not collected, either as a result of equipment failure, lack of equipment availability or exceeding funding limits. Particulate measurement was only achieved on two occasions due to availability of the device and the cost of the device.

Research Site Visits & Measurement Summary								
Measured Parameter	**BSRIA**				**5 Plus Architects**			
	Spring	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**
Temperature*	✓	✓	✓	✓	✓	✓	✓	✓
Humidity	✓	✓	✓	✓	✓	✓	✓	✓
CO_2	✓	✓	✓	✓	✓	✓	✓	✓
Lux - Vertical	✓	✓	✓	✓	✓	✓	✓	✓
Lux - Horizontal	✓	✓	✓	✓	✓	✓	✓	✓
Noise	✓	✓	✓	✓	✓	✓	✓	✓
Particulates	×	×	×	✓	×	×	×	
Breathing rate	×	✓	✓	✓	×	✓	✓	✓
Heart rate	×	✓	✓	✓	×	✓	✓	✓
Skin Temp’	×	✓	✓	✓	×	✓	✓	✓
GSR^	×	✓	✓	✓	×	✓	✓	✓
Blood Oxygen	×	✓	✓	✓	×	✓	✓	✓
Metabolic rate	×	✓	✓	✓	×	✓	✓	✓
Activity	×	✓	✓	✓	×	✓	✓	✓

***** *Includes Black Globe measurements* **^** *Galvanic Skin Response*

Table 27 - Site Visit Frequency and Measured Parameters

3.8.2.14 Temperature and Humidity (T&D) Device

Supplied with external sensors, the device mounted at the top of the EMP (1800mm) was a T & D Corporation RTR-503 Wireless Thermo Recorder. The unit was provided with a combined external calibrated temperature and humidity sensors and was configured as an "endless" data logger for each seasonal site visit. Numbered sequentially as units 1-4, a total of four RTRE-503 units were provided, Table 28 details the specification of each unit.

T & D Corporation RTR-503 Wireless Thermo Recorder	
Characteristic	**Specification Value**
Channels	2ch - (x1 Temperature) + (x1 Humidity)
Sensor	Thermistor (t°c) Polymer Resistance (%rh)
Units	°C or °F %RH
Range	0-55 °C 10-95 %RH
Accuracy	+/- 0.3 °C +/- 5 %RH (at 25 °C – 50 %RH)
Recording Mode	Programmed Endless data recording
Recording interval	Selective 1-30 sec or 1 – 60min. (2min selected)
Communications	Wireless + Optical
Battery (Life)	Lithium battery (10-months)
Environment	-40 to 80 °C (IP 64)

Table 28 - RTR-503 EMP Temperature & Humidity Data-logger Specification

A two-minute recording interval was selected to maximise the data capture and provide significant granularity for statistical review. The RTR-503 maximum memory size was 8-days using the 2-min recording interval and so met the 5-day site monitoring time frame.

3.8.2.15 Temperature, Humidity & CO_2 (T&D) Device

This particular device was mounted at the average measured head height of a sitting person (1200mm) and was a T & D Corporation RTR-576 temperature, humidity and CO_2 monitor The unit was provided with a combined external calibrated temperature and humidity sensor connected via a jack plug connection and used an internal NDIR CO_2 sensor. The unit was again configured as an “endless” data logger with 2-minute recording intervals for each seasonal site visit. Table 29 provides the specific characteristics of the unit.

A two-minute recording interval was selected to maximise the data capture and provide significant granularity for statistical review. The RTR-503 maximum memory size was 8-days using the 2-min recording interval and so met the 5-day site monitoring time frame. Due to the additional CO_2 measuring capability the units internal battery was unable to support recording past 2-days, therefore a secondary mains a.d/d.c power supply unit was connected. Four RTR-576 units referenced 5-8 were provided, and fitted to the EMP using a specially supplied aluminium cradle.

Measurements of CO_2concentrations are affected by atmospheric pressure, therefore when accuracy is required, it is recommended that atmospheric pressure correction is carried out. The unit uses an automatic calibration feature within the supplied software to auto calibrate the unit, which based upon the set altitude level inputted by the user – for Bracknell we used an altitude of 70.0m a.s.l and for Manchester 77.0m a.s.l. The scale and difference in altitude was not considered to affect the overall measured values.

T & D Corporation RTR-576 Wireless CO_2 Recorder	
Characteristic	**Specification Value**
Channels	3ch - (x1 Temperature) + (x1 Humidity) + (x1 CO_2)
External T/H Sensor: (THA-3151)	Thermistor (t^{o}c) Polymer Resistance (%rh) NDIR (Non Dispersive Infra-Red - CO_2 ppm)
Units:	^{o}C or ^{o}F %RH CO_2 ppm
Range:	0-55 ^{o}C 10-95 %RH 0-9,999 CO_2 ppm
Accuracy:	+/- 0.3 ^{o}C +/- 5 %RH (at 25 ^{o}C – 50 %RH) +/- 50 ppm + 5% of reading @ <5,000 ppm
Recording Mode:	Programmed Endless data recording
Resolution:	0.1 ^{o}C 1 %RH 1 ppm
Recording interval:	Selective 1-30 sec or 1 – 60min. (2min selected)
Communications:	Wireless + Optical
Battery (Life):	Lithium battery (10-months)
Environment:	0 to 45 ^{o}C (IP 64) <90 % RH zero condensation

Table 29 - RTR-576 EMP Temperature & Humidity and CO_2 Data-logger Specification

The UK CO_2 unit supplier conducted annual calibration of each unit, however, prior to each of the seasonal site visits, each unit was placed externally to assess the accuracy of calibration. External air contains approximately 400-450ppm CO_2 which is considered as the normal average atmospheric concentration level (a.c.l) for CO_2.

All units when tested in external fresh air displayed measured CO_2 values ranging between +/-10% difference in a.c.l (400ppm) during a 10-min period. All units were therefore considered to be within their annually calibrated values. The units were are also provided with an auto calibration facility, measuring the lowest recorded CO_2 values (building empty) against a defined OEM a.c.l.

3.8.2.16 Temperature, Humidity & Illuminance (T&D) Device

This particular recording unit was a T & D Corporation RTR-574 temperature, humidity and Illuminance monitor and was located on each EMP at 700mm a.f.f.l to avoid conflicting with the locations of the temperature, humidity and illumination sensors. The illumination sensor itself was mounted at the average measured head height of a sitting person of 1200mm, while the temperature and humidity sensor was located at a torso height of 800mm.

The combined temperature/humidity sensor (THA-3151) and the Illuminance sensor (ISA-3151) were connected to the RTR-574 unit using individual jack plug connections. Table 30 provides the specific characteristics of the unit. A two-minute recording interval was selected to maximise the data capture and provide significant granularity for statistical review. The RTR-503 maximum memory size was 8-days using the 2-min recording interval and so met the 5-day site monitoring time frame. The illumination sensor was positioned vertically to obtain a vertical light (lux) level, this was in addition to the average horizontal light (lux) level measured within the centre of the research space.

Within both locations the majority of work tasks related to P.C screen work, therefore, we were particularly interested to assess local vertical light levels, and to compare these to the horizontal light (lux) levels, assessing this relationship to typical design values.

T & D Corporation RTR-574 Wireless Illuminance UV & Thermo Recorder	
Characteristic	**Specification Value**
Channels	4ch - (x1 Temperature) + (x1 Humidity) + (x1 Illuminance) + (x1 Intensity UV)
Sensor	Thermistor (t°c) Polymer Resistance (%rh)
Units	°C or °F %RH
Range	0-55 °C 10-95 %RH 0-130,000 lux (Illuminance sensor) 0-30mW/cm^2
Accuracy	+/- 0.3 °C +/- 5 %RH (at 25 °C – 50 %RH) Illuminance +/- 5% UV Intensity +/- 5%
Recording Mode	Programmed Endless data recording
Recording interval	Selective 1-30 sec or 1 – 60min. (2min selected)
Communications	Wireless
Battery (Life)	AA Alkaline (4-months)
Environment	0 to 55 °C -10-60 °C (illumination sensor)

Table 30 - RTR-574 EMP Illumination Temperature & Humidity Data-logger Specification

3.8.2.17 Temperature, Humidity (Tiny-tag) Device

This particular device was mounted at 200mm a.f.f.l and was a temperature and humidity monitor with integral sensors. This unit was not a wireless unit therefore data was downloaded via DIN lead to a PC and transferred to an xls format via the OEM software. A two-minute recording interval was selected to maximise the data capture and provide significant granularity for statistical review. The Tiny-tag maximum memory size was 22-days using the 2-min recording interval and so met the 5-day site monitoring time frame.

3.8.2.18 Data Transfer & Analysis

The Tiny-tag device and T & D Corporation devices were provided with their OEM software to enable the data to be downloaded and transferred to xls format for detailed statistical analysis. All measured data is deposited within “Research Fish” logically filed and scheduled.

The T & D Corporation devices were provided with a single wireless controllers and receiver to programme each device, start, stop and download data collection from a central off site location. Each EMP device was allocated a “Unit No.” to which the central hand-held controller communicated. The receiver range was <500m, consequently their was no intrusion into the workspace when down-loading data. The data was transferred to the P.C OEM software via a DIN lead and archived within the software under each individual unit reference number.

Once transferred to Microsoft xls (2007) format, each data set was cleansed and validated for individual extreme values, data anomalies, appropriate delimiters and date references. Each data set was then subsequently analysed statistically and graphically to present a visual and numerical view of the values and trends (ref. Chapter 6).

The individual data sets from each EMP, and at each installed level was subsequently correlated with each individual Sensewear armband measured value, and each of the measured values selected from the Hidalgo vest. Table 31 indicates a data analysis matrix across all measured parameters. The graphical and statistical results are provided within Chapter 6 including a descriptive and interpretive narrative.

All devices were calibrated by the OEM's, with certified calibration certificates issued across the research periods. Re-calibration was necessary due to the extended research periods, and one particular unit failed catastrophically (Unit 12) and needed to be replaced (Unit 12xx).

IEQ & Physiological Measured Parameters							
Measurement		Temperature	Humidity	Light (Lux Level) Horizontal and Vertical	Carbon Dioxide (CO_2)	Noise	Particulates
Heart Rate		✓	✓	✓	✓	✓	×
Breath Rate		✓	✓	✓	✓	✓	×
Blood Oxygen		×	×	×	×	×	×
Skin Temp		✓	✓	✓	✓	✓	×
GSR		✓	✓	✓	✓	✓	×
Body Heat Flux		✓	✓	✓	✓	✓	×

Note: Blood Oxygen Levels provided no discernible change in value and were not processed

Table 31 - Measured Parameter Comparison Matrix

3.8.2.19 Equivital Life Monitor Vest

The Equivital Life Monitor (ELM) was selected to measure and record a single volunteers heart rate, breathing rate, skin temperature and blood oxygen level. The adoption of a single volunteer was based upon the limited equipment budget available, and the difficulty in maintaining accurate responses from 8 individual volunteers. Early trials discovered the vests worn by the volunteers were uncomfortable for both the women and the men, and the various body shapes in a number of cases were not conducive to comfortably wearing the vest and the connecting leads. In addition, it was discovered that the integral electro cardio graph (ECG) pads needed to be kept moist to make effective skin contact, so were found to be disruptive to the volunteers work task. The use of the research engineer within the research space was therefore considered the best alternative, as the RE was able to view the performance of the vest real time via a Bluetooth connection, and who could then make corrections and adjustments as necessary.

Calibration of the ELM was not required as stated by the manufacturer due to the nature of the physiological monitoring. In the case of the breathing rate and heart rate, the ELM measures the raw waveforms then using a calculation algorithm within the software calculates the breathing and heart rates indicating the results in breaths and beats per minute respectively. Within the software the OEM also embeds an automatic data quality check in order to provide a low/high confidence measure for each monitored parameter. For example, If the vest was not fitted to the body correctly or the ECG electrodes had degraded over time or through washing, or over use, then a low confidence value would be reported and alarmed. This is also reflected in the reported 'Physiological Welfare Index'. The *"physiological welfare index (PWI)"* which is a calculated measure of two of the measured parameters, and is used to determine the wearers expected welfare and state of being.

Environmental sensors that measure the specific concentration levels of a compound, either a liquid or a gas do in fact need to be calibrated, this is because In these types of sensors, calibration is generally required because of the drift or % change within the electro thermal sensor that occurs with age, use or damage.

To measure the blood oxygen saturation levels within each volunteer, the Nonin ear lobe monitoring sensor was selected. This sensor was selected in lieu of a finger sensor typically seen in use within hospitals as it allowed the wearer to continue with their task, either writing, drawing or keyboard work. Depending upon the location of the sensor (finger or ear), it is known that different levels of blood oxygen will be detected. When using the finger as a sensing point, this location is subjected to artifact hand moving or reduced circulation errors, therefore will generally be lower than readings observed on the ear. This is exactly the discovery made during our own data measurements.

3.8.2.20 Sensewear Armband

To measure the volunteer physiological characteristics, the Sensewear patient monitoring armband was selected. The Sensewear armband has been used within similar previous research studies (Keeling 2015, Liu 2012) and provides measurements of the volunteers skin temperature, galvanic response (stress Level), body heat flux and a calculated metabolic exchange rate.

Used ostensibly in medical practice, the armband is worn under clothing on the upper left arm with direct contact to the skin. Using proprietary software, each armband is allocated to an individual research volunteer with their specific body characteristics uploaded into each device.

Each armband is provided with an integral re-chargeable battery with a charge rating of approximately 72hrs from a single charge. This therefore, necessitated the armband to be re-charged by the volunteer each day to maintain the integrity of the 5-day research period. Chapter 5 provides further detailed daily data capture examples.

Four Sensewear armbands were procured to cover both research sites, requiring each of the armbands to be cleansed of all data post each site visit, Prior to issue the next set of volunteers the armbands were washed and bacterially cleaned then re-configured with the next set of volunteer details. Four volunteers were maintained at each site, however, one site (BSRIA) required a change of volunteer due to resignation.

The armband is provided with its own OEM software in order to process the data. All data was downloaded at the end of each 5-day period using a standard OEM supplied DIN USB lead connection enabling statistical and graphical representation to be completed. The data is characterised and translated into Microsoft xls format, tabulated, graphically represented and presented within Chapter 5. All data is time and event stamped, and was manually cleaned and validated using graphical representation to locate any outlier data points.

3.9 Hand-held Environmental Monitoring Equipment

In addition to the fixed measuring poles located at each desk location, a range of hand held monitoring devices were utilised to provide a spot value assessment of the general research area during the 5-day 24x7 period. The following environmental equipment was deployed at both research locations:

3.9.1 Heat Stress Meter

The Extech HT30 Heat Stress meter was selected to measure 4 specific readings during five different periods throughout the day. Chapter 4 provides a review of the data captured. This device was used to compare readings against the environmental monitoring poles and the general area temperature and humidity devices. The device is normalised for external use (full sun) or internally (no sun) and possess four measuring parameters.

This particular temperature & humidity meter, provides an overall validation of the area being monitored, but it also provides black globe measurements to assess the overall temperature inclusive of contributory surrounding radiant factors.

Black Globe Temperature & Humidity Meter Specification	
Wet Bulb Globe Temperature (WBGT) range	0- 50 deg.C
WBGT accuracy	Calculated from other factors (see eq…)
Black Globe Temperature (Tg) range	0 – 80 deg.C
Tg accuracy (Indoor)	+/- 2 deg.C
Air Temperature range (Ta)	0 – 50 deg,C
Ta accuracy	+/- 1 deg.C
Relative Humidity (RH)	0 – 100%
RH accuracy	+/- 3% at 25 deg.C (10 - 95%)
Resolution	0.1 deg.C / 0.1% RH
Operating Temperature	0 – 50 deg.C
Operating Humidity	80% RH
Manufacturers Data	http://www.extech.com/instruments/product.asp?catid=37&prodid=158

Table 32 - Black Globe Temperature Meter Characteristics

The Wet Bulb Globe Temperature (WGBT) or heat stress index indicates how hot the environment feels when humidity is combined with temperature, air movement, and sunlight.

$$WBGT = 0.7Tw + 0.2Tg + 0.1Ta$$

Tw = wet bulb temperature (Humidity and (Ta) air temperature combined)

Tg = black globe temperature (Mean Radiant Temperature MRT)

Ta = Normal air temperature (The kinetic or motion energy within air)

Air temperature *(Ta)* is a measure of how warm a volume of air has reached, and indicates the kinetic or motion energy within a given volume of air.

Relative Humidity (RH%) is the amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature. If the air is at 100-percent relative humidity then sweat will not evaporate into the air. As a result, we feel much hotter than the actual temperature when the relative humidity is high. Relative humidity is an important characteristic for thermodynamic heat transfer.

Black Globe Air Temperature (TG) or Mean Radiant Temperature measures the contributory effect of radiant heat from the immediate surroundings, but remains a factor of air temperature. The MRT is a contributory measure and calculated value using the following expression;

$$MRT = \left[(GT + 273)^4 + \frac{1.1\ x\ 10^8 x\ Va^{0.6}}{\in\ x\ D^{0.4}}\ (GT - Ta)\right]^{1/4} - 273$$

MRT = *mean radiant temperature (°C)*
GT = *globe temperature (°C) - measured*
Va = *air velocity at the level of the globe (m/s)*
ε = *emissivity of the globe (no dimension)*
D = *diameter of the globe (m)*
Ta = *air temperature (°C)*

The use of the heat stress meter facilitates a more accurate understanding of how MRT relates to the way we need to consider how the human body dissipates heat. The human body dissipates heat through 4-primary means:

1) Varying the rate and depth of circulation;
2) The sweat glands
3) Through the skin as sweat or perspiration
4) The respiratory system through exhalation.

Heat loss via the skin accounts for <90% of the bodies heat loss, therefore it is important to provide a thermal exchange mechanism between the occupants body and that of the surroundings. Sweating on its own is not an efficient mechanism as it relies upon evaporation, and during periods of high relative humidity evaporation is constrained by the humidity within the surrounding air. Heat is also exchanged trough breathing, as the lungs act as an internal liquid to air heat exchanger. The sensors utilised on the EMP's however, only measured air temperature (*Ta*) and consequently the use of the Heat Stress meter was considered an appropriate means to verify any correlations.

3.9.2 Sound Power Meter

The Extech SDL 600 Sound Power level meter was selected to measure the overall sound level. Selecting frequency weighting "A" as defined within IEC 61672 was selected, we reflect more closely the ears interpretation of noise and therefore we can align our measurements with occupant survey responses. The use of an "A" weighting and "Fast" response noise setting is commonly used when assessing environmental noise levels, particularly when instantaneous peaks may occur within a workplace environment. The device was located within the centre of the room and configured with 120s recording interval and 24x7 operation. Table 34 indicates the meter specification.

Noise Meter Specification	
Microphone	12.7mm electret condenser microphone
Units	Decibels
Ranges	(30-80) (50-100) (80-130) db
Frequency Range	31.5Hz to 8KHz
Frequency Weighting	A & C
Time Response	Fast (125ms); Slow (1s) selectable
Sampling Rate	Auto (120); 1, 2, 5, 10, 30, 60, 120, 300, 600, 3600s
Applicable Standards	IEC 61672-1: 2002 Class 2; ANSI S1.2: 1983 Type 2
Operating Temp Range	0 – 50 deg.C
Operating Humidity	85% RH (max)
Manufacturers Data	http://www.extech.com/instruments/product.asp?catid=18&prodid=680

Table 33 - Extech Noise Meter Specification Details

3.9.3 CO_2 Humidity Temperature Data Logger

The Extech SD 800 CO_2/Humidity/Temperature data-logger was selected to monitor the overall research area. This selection provided a comparative measure against the data loggers located on the EMP's. The unit is provided with a separate plug and play CO_2 sensor but has an internal temperature & humidity sensor. The meter was configured with a 120s recording interval and continuous recording 24x7 for the duration of the site. Table 35 indicates the meter specification.sit.

CO_2 Humidity & Temperature Meter Specification	
Temperature sensor	
Relative Humidity sensor	Precision Capacitance Type
CO2 Sensor	NDIR (Volume)
Temperature sensor range	0 – 50 deg.C (resolution 0.1 deg.C)
Relative Humidity sensor range	10 – 70 – 90 % (resolution 0.1%)
CO2 Sensor range	<1000 - <3000 - >3000ppm (resolution 1ppm)
Selectable Data Sampling rate	Auto, 5, 10, 30, 60, 120, 300, 600s
Temperature sensor accuracy	+/- 0.8 deg.C
Relative Humidity sensor accuracy	+/- 4%
CO2 Sensor accuracy	<1000 (+/- 40ppm); <3000ppm (+/-5%); >3000ppm (+/- 250ppm)
Operating Temperature	0 – 50 deg.C
Operating Humidity	<90%
Manufacturers Data	http://www.extech.com/instruments/product.asp?catid=37&prodid=628

Table 34 - Extech CO2/Humidity/Temperature Meter Specification Details

3.9.4 Illumination (Light Meter)

The SDL 400 light meter was selected to provide a general horizontal Illuminance, and was located within the centre of the research area with close proximity to the environmental poles. The horizontal Illuminance is assessed against the vertical Illuminance levels measured on each environmental monitoring pole and is compared to standard UK and global guidelines. The unit of measure selected is the “Lux” which reflects the current industry standards referenced within Chapter 2. The meter was configured for 120s recording interval and 24x7 operation. Table 35 indicates the meter specification.

Illumination (Light) Meter Specification	
Sensor Types	Colour corrected dome type CIE compliance
Sampling Rate	Auto, 1, 2, 5, 10, 30. 60, 120, 300, 600 1800, 3600s
Range	<2000; <20,000; <100,000lux
Resolution <2000lux	1 lux
Resolution <20,000lux	10lux
Resolution <100,000lux	100lux
Accuracy	+/-4%
Operating Temperature	0 – 50 deg.C
Operating Humidity	85% max
Manufacturers Data	http://www.extech.com/instruments/product.asp?catid=10&prodid=677

Table 35 - Extech SD 400 Light Meter Specification Details

3.9.5 TSI Particulate Meter

As part of an overall IEQ assessment approach, air quality is a fundamental aspect to consider and to investigate. To investigate further the air quality within each research site, the TSI 9306-02 was hired form BSRIA Hire Solutions Ltd. The unit sample size ranged form 0.3; 0.5; 1.0; 3.0; 5.0; 10 μm and the unit was configured to operate 24x7. The meter was set up with a ∞ infinite time sampling period, a sample period of 60s and a hold interval period of 120s. The data was extracted using the OEM software to an xls format to allow correlation of the data across other independent IEQ variables. The device uses a light scattering laser diode light source to measure the particulates drawn into the unit using an internal vacuum pump and Isokinetic sampling probe.

3.10 Measuring Instruments - Calibration Methods

The OEM supplier annually calibrated each EMP measuring unit meter) and hand-held measuring devices as follows:

3.10.1 Temperature and Humidity meters

Calibration was performed in a closely controlled and monitored environmental chamber with known values of uncertainty. The temperature scale used to calibrate the devices was ITS-90. Temperature was calibrated at three temperature and humidity levels - 10^{o}C/80%RH; 20^{o}C/50%RH; and 30^{o}C/30%RH using tolerance values of 0.8^{o}C/4%RH. A % out of specification <90% is considered acceptable, however values >90% require the device to adjusted and re-calibrated.

3.10.2 Heat Stress Meter

Calibration was conducted within a sealed environmental chamber along a series of reference resistance thermometers & hygrometers with known values uncertainty. The average of these reference devices was used as the applied temperature value. The meter was calibrated using the IN function characteristic set within the meter and compared to the ITS-90 temperature scale. The meter was calibrated for air temperature, black globe temperature and humidity. The applied temperature values (At and Tg) at 10^{o}C; 20^{o}C; 30^{o}C were calibrated using 1% and 2% tolerances respectively. Humidity applied values were 30; 50; and 80%RH with tolerances of 3% across the range.

3.10.3 CO_2 Meter

Gas concentration calibration was performed within a sealed zipped bag enclosure using a known volume and quantity of both nitrogen and CO_2. Concentrations of CO_2 were introduced to the sensor at 0; 500; 1000; 2500 ppm using tolerance values of 0/40; 500/40; 1000/50; 2500/125 ppm. A % out of specification <90% is considered acceptable, however values >90% require the device to adjusted and re-calibrated. Readings were taken following stabilisation of the readings on the device.

3.10.4 Illumination Meter

Calibration was performed to BS667 using a tungsten filament lamp with a colour temperature of 2856k. The meter was calibrated using reference instrumentation of known uncertainty, and the light meter under calibration was zeroed within a completely blacked out room. Illuminance levels within the room were calculated at various intervals along the calibration frame, and in conjunction of the inverse square law for distance from a constant tungsten filament lamp source. Applied light values/tolerances (lux/lux) 0/2; 5/2.2; 10/2.4; 20/2.8; 50/4; 100/6; 200/10; 500/22; 1000/42, 2000/82 were applied to the meter, reading were taken from the meter and compared with the calculated reference instruments.

3.10.5 Noise meter

The meter was calibrated annually to BS EN 61672-1:2003 using a known calibrated sound generator at a setting of 1kHz. A pre-calibration check at 1Khz was performed across the acoustic dB range 30-130dB. Within the auto range A-weighting filter mode, 1kHz fast response setting, the applied acoustic dB noise generator was applied to the meter at 94dB; 105dBa and 115dB. Tolerances were calculated at 1.4 dB across for the three applied values. In addition the meter was tested at a typical 94dB(A) at 125Hz; 1kHz and 4kHz. The same was applied to the meters dB(C) weighted range. A % out of specification <90% is considered acceptable, however values >90% require the device to adjusted and re-calibrated. Readings were taken following stabilisation of the readings on the device. In addition, the meter is calibrated prior to each use using a hand held 94dB calibrator unit placed over the microphone. The meters internal "CAL" potentiometer is adjusted to agree with the calibrator output noise level (94dB).

3.10.6 Particulate Meter

The OEM supplier calibrates the unit annularly using a clean chamber rig incorporating polystyrene latex spheres of known diameter introduce to the unit and calibrated test rig monitor. The unit readings are verified with the calibrated test rig and the unit cleaned and adjusted accordingly. In addition to the annual calibration a daily calibration test is conducted by connecting a known HEPA filter to validate a zero reading through the HEPA filter.

3.11 Stage 3 - Measurements & Surveys

Each discrete data collection work-stream was conducted sequentially to maintain a focused approach to data management. The application of each work-stream was undertaken in close collaboration with each research site representative, and was subjected to extensive planning, review and consultation.

3.11.1 Surveys and Semi-structured Interviews

POE surveys had not previously been undertaken at either of the research sites, therefore this new data collection was the first such feedback associated with both workplaces. The collected POE, AHP and semi-structured surveys were prepared discretely for analysis, tabulated using xls table format and filed under each respective survey method. No analysis was undertaken until all the collected data had been cleansed and scheduled into the discrete seasonal week research periods.

3.11.2 IEQ and Physiological Measurements

Again no previous monitoring had been conducted at either research site, therefore, no previous measurements existed to benchmark our own measured values. The use of the EMP's and area monitoring equipment required best available coincident time stamping to be achieved, and each monitoring unit was matched to the laptop time clock where possible. To avoid any time discrepancies the interval times were set at 2min intervals to provide a very close correlation of data subject to the installed time clock. The only exception to this time stamp correlation was the Equivital sensory vest which was prone to low data confidence issues and software functionality. The use of an alternative product for similar studies is advised.

3.11.3 Research Ethics and Health & Safety Obligations

Due to the nature of the research needing human involvement and for personal data recording and storage, the research was conducted under the strict rules governing ethical research set by the University of Reading. A fully detailed ethics application pack was submitted and subsequently approved by the University of Reading Ethics Committee. A copy of the submitted ethics application is contained within Appendix A.

In addition to ethics approval, it was also necessary to submit a project health & safety report prior to conducting any field research. The method of research required the deployment of research equipment within 3rd party workplace environments inclusive of travel and logistics between sites, therefore potential risks existed which needed to be reviewed and mitigated. The use of 240v power supplies via extension lead for example and the use of power tools to fit the EMP's needed to be considered with all risks mitigated before proceeding. A copy of the submitted health & safety review form is contained within Appendix B.

3.12 Stage 4 - Research Analysis

Under Stage 4, the five data collection work streams were reduced into three discrete analytical task areas.

1. The Analytic Hierarchy Process survey analysis
2. SME semi-structured interview review
3. POE and measured physiological & IEQ analysis

During Stage 4 measured physiological and IEQ data were correlated, and the POE survey responses were subjected to descriptive and inferential statistical analysis.

The adoption of such detailed and extensive data collection necessitated the use of a number of proprietary software tools, either to transfer data between analytical formats, or to provide analysis across or between different data sets. The following software tools were adopted or considered:

1. Transparent Choice – Analytical Hierarchy Process (AHP) software.
2. NVIVO – Analysis of semi-structured interview transcripts.
3. Minitab – Statistical *inferential* analysis - Pearson's r Correlation Coefficient
4. Microsoft Excel (xls) – Statistical *descriptive* analysis
5. Tiny-tag – OEM data management & transfer to xls format
6. T & D Corporation – OEM data management & transfer to xls format
7. Sensewear Inc. – OEM data management & transfer to xls format
8. Hidalgo Life Monitor Inc. – OEM data management & transfer to xls format
9. TSI 9306 Particulate Meter - OEM data management & transfer to xls format

The AHP software selection was particularly complicated given the many sources available, however, a package supplied by Transparent Choice, was eventually selected following a scoring matrix review (Table 36). A full market assessment and free trials were undertaken in the selection of the AHP software tool, however, the NVIVO transcription software was selected as a result of literature review, and Minitab was selected on the recommendation of the Statistical Centre at the University of Reading. The AHP software was eventually not adopted and a manual alternative deployed.

Analytical Hierarchical Process Software Suppliers														
Supplier	Transparent Choice		Sourceforg		Creative Decisions Foundation		BPSGM		True North Software		Expert Choice		Qualica	
Product Name	Transparent Choice		PriEst		Super Decisions		N/A		N/A		Comparion		N/A	
Product & Research Criteria	✓✗ Score 1-5		✓✗ Score 1-5		✓✗ Score 1-5		✓✗ Score 1-5		✓✗ Score 1-5		✓✗ Score 1-5		✓✗ Score 1-5	
Export to Excel/Word	✓	5	✓	3	✓	5	✗	1	✗	1	✓	5	✓	5
Clear Formats	✓	5	✗	3	✓	5	✗	3	✓	5	✓	5	✗	3
Research Alignment	✓	5	✗	3	✗	3	✗	3	✗	3	✓	5	✗	2
Graphical editor	✓	5	✗	1	✗	3	✗	1	✗	1	✗	3	✗	3
Ease of Data Input	✓	5	✗	3	✗	2	✗	3	✗	2	✓	5	✗	3
Cost v Budget <£400	✓	5	✓	5	✓	5	✓	5	✓	5	✗	1	✓	5
Pairwise Comparison	✓	5	✓	□	✓	5	✓	5	✓	□	✓	5	✓	5
Accept model changes	✓	5	✗	1	✗	3	✗	1	✗	1	✓	5	✓	5
Inconsistency monitoring	✓	5	✓	5	✗	3	✗	1	✗	1	✓	5	✓	5
Sensitivity Analysis	✓	5	✓	5	✓	5	✓	5	✓	5	✓	5	✓	5
Software Support	✓	5	✗	1	✓	5	✗	1	✗	1	✓	5	✓	5
Desktop solution	✗	2	✓	5	✓	5	✓	5	✓	5	✗	2	✓	5
Total Score	✓	57		40	✓	49	✗	34	✗	35	✓	51	✓	50
Max. Possible Score	**60**													

Table 36 - AHP Software Selection Scoring Matrix

The respective measuring & recording equipment OEM's described with Section 3.6 and 3.7 supplied their own software enabling xls data transfer from equipment to laptop.

3.12.1 Data Analysis, Techniques & Tools

Data analysis was structured into quantitative and qualitative data sets from the output of the various tools and site measurement collected data. The semi-structured interviews provided qualitative as well as coded quantitative output from the NVIVO software, the AHP survey provided quantitative calculated weighting factors across the AHP qualitative survey responses, and the use of descriptive and inferential statistics was adopted to review the collected survey data and IEQ measured values.

Within and between the two research sites, mean, minimum, maximum, mode and variance (SD^2) values are calculated across all measured empirical data to assess any specific variance over time.

The use of statistical correlation coefficients; Pearson's product moment (r), and coefficient of determination (r^2) have been adopted to assess the relationship between the various independent variables, and the amount of % variance imposed across each set of variables.

Analysis of variance (ANOVA) was used to test for statistical significance between the differences in means of selected data set groups. The use of t-test was also used to determine if the means of two different measurement groups differed to a significant degree. Both statistical tests are discussed further within Chapters 6.

When applying criteria weighting across SME's, a factor of controversy and uncertainty exists, but this is primarily as SME's are like others, in that sometimes they are unaware or change their preferences from time to time (Chen et al 2010). A further issue lies in how well AHP survey participants understand the priority ranking questions (Saaty et al 2006), however, the RE structured the questionnaire to simplify the ranking response and provided extensive description prior to completing.

Sensitivity analysis (SA) is defined as the study of how the variation in the output of a model numerical or otherwise can be validated qualitatively or quantitatively to different sources of variation. Any model depends upon the information fed into it (Salateli 2002), therefore in analysing the AHP responses (only), three SA checks were undertaken.

1. Reducing the individual group sample response size by a factor of -1 until an effect was observed.
2. Priority rankings obtained from the various SME's were averaged by organisation and then averaged as a whole SME group.
3. The resultant group averages were used as an average multiplication factor to each SME question response.

Previous studies using AHP analysis have used SA (Chang et al 2007; Kousalys et al 2013; and typically they have been applied to criteria weighting post AHP calculation (Eigen Value). However the most common method is to change the subjective preferences of the survey responses, and only then to calculate their influence upon the final calculated weights/priorities. The AHP model was run a further three times to assess the possible impacts to the final priority weighting results.

3.13 Stage 5 - Discussion & Review

During Stage 5, AHP priority rankings and SME semi-structured NVIVO software results were compared using comparative analysis. The SME semi-structured interview questionnaire was designed specifically to seek the views across a number of known IEQ factors, enabling the AHP results and NVIVO output to be used to assess where possible relationships or conflicts existed.

Each POE survey is compared against the other sites, not to assess the actual performance of each site, but to review which issues are considered more relevant and subsequently more important to overall feelings of satisfaction. The result of this review is then used to assess potential relationships or gaps across the SME AHP responses and those of the transcribed semi-structured interviews.

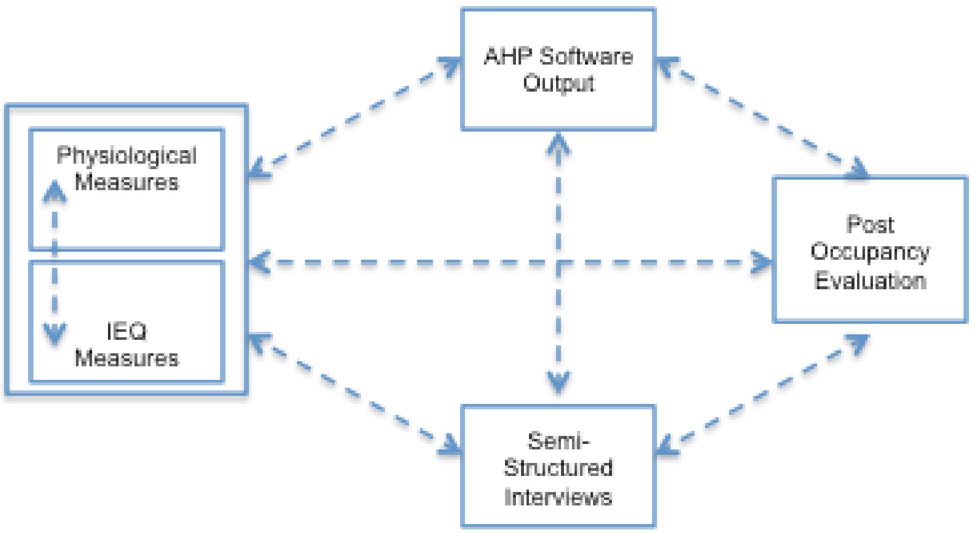


Fig.36 - Comparative Data Output Relationship Model

The physiological and IEQ measured statistical review having been correlated within Stage 4, assess the relationship between each independent variable as measured. The results of these correlations are then analysed in associated with the POE, AHP and semi-structured interview response to investigate ant potential relationships. The intent of this comparative analysis (Fig.36) is to support the research hypothesis that expectations and aspirations of designers differs from workplace occupants, and the introduction of an enhanced post occupancy evaluation model will help to close the building energy (in use) performance gap.

3.14 Chapter Summary

This chapter describes a staged and sequenced research methodology designed to support the research objectives. Based upon quantitative and qualitative data collection methods, our research combines a positivism and constructivism philosophy, adopting both an inductive and deductive approach to data analysis.

In respect of the specific research strategies, we use a multi-method choice incorporating experimental, action and case study strategies. In addition grounded theory, surveys and archival strategies are also incorporated as part of the multi-model approach.

Due to the availability of the research sites, and the need not to intrude into the functioning of business operations, a cross sectional research approach was selected. This was applied across the POE and AHP surveys and the semi-structured interviews with the results compared and analysed across the surveyed sites. IEQ measurements were conducted over 4 seasonal week-long periods of 5-days Mon – Fri, and 4 volunteers were made available at both the research sites located at BSRIA (Bracknell) and 5 Plus Architects (Manchester).

At each site IEQ factor measurements *(CO_2; temperature; humidity; light level; noise; particulates)* were collected 24x7 for each 5-day period, and physiological measurements were collected from four volunteers at each site *(skin temperature; GSR; body heat flux) during each day.* Other physiological measurements *(heart rate; breathing rate; blood oxygen)* were also taken form the RE each day.

Chapter 4 - Qualitative Applied Survey Analysis

4.1 Introduction

As detailed within Chapter 3 Research Methodology, the research framework uses a quantitative empirical data review and a qualitative survey approach. The survey approach adopted (x3) techniques to gather data across technical subject matter exerts and building occupants.

1. AHP ranking and rating survey administered by the R.E with the subject matter expert field volunteers to assess the importance of (x109) individual building characteristics. (see Appendix C for sample questionnaire.)
2. Semi-structured interviews undertaken with the subject matter expert field volunteers at the same time as the AHP survey. The survey covered (x10) questions. (see Appendix D for sample questionnaire.)
3. On-line (Bristol On-line) survey covering (x25) questions and developed to seek a workplace user view of occupying the space.

The surveys were conducted as detailed within Table 37.

Surveyed Organisations				
Organisation	AHP	Semi-Structured	On-line IEQ	Comments
5Plus Architects	(8)	(5)	(26)	Building Architects
BSRIA	(8)	(4)	(58)	Building Research
Hurley Palmer Flatt	(8)	(5)	N/A	Engineering Consultant
Vertex Ltd	(5)	(5)		Building Maintenance
Totals	(29)	(19)	(84)	

Table 37 - Surveyed Organisations – Issued and Responded

Statistically the R.E was unable to achieve the 345 No. (Z-score derived) surveys to satisfy a 5% Confidence Level (CL) for the survey data analysis. This was due to RBS cancelling the research (end year-2) and a number of other selected sites unable to deploy the surveys for business reasons. The survey results are therefore taken as a base for future wider survey research and are not statistically representative.

4.2 Semi-Structured Interviews

The semi-structured interviews were developed around 10-key questions to reflect the responses obtained through the on-line surveys, but also with a future of focus of assessing the view for connecting the person to the building via suitable feedback systems.

1. *Many organisations invest heavily in providing clean fresh air to the building occupant, would you say you can appreciate or understand this investment and can you tell the difference between the outside air before you arrive at work and the air provided by the HVAC system.*

2. *In terms of the lighting system installed within your workplace would you say it is of suitable design and quality, and do you believe artificial lighting and day-lighting should be mutually inclusive i.e. designed and controlled together? What benefits do you think this would deliver to you as a building occupant?*

3. *Thermal Comfort has long been the biggest Helpdesk issue for many organisations, do you believe a solution lies in providing systems with direct occupant control and systems that can learn intelligently.*

4. *As a building user would you like to see more intelligent building controls being offered to the occupant, if so what would you like to see controlled and through what access would you prefer e.g. IPhone, Tablet; Remote connection; Intelligent sensors embedded on the occupant, or even intelligent manual intervention.*

5. *Do you think your organisation should adopt a consistent set of standards for the workplace such that it looks and feels the same wherever you are in your organisation?*

6. *What facets of the workplace do you believe are the most important for occupant satisfaction and well-being?*

7. *Is noise or vibration a major issue in the workplace reference to distractions, and/or the inability to conduct your work task? Do you have any current noise or vibration issues and if so how have you mitigated those issues?*

8. *Sick Building Syndrome is a commonly used phrase within the property industry to define a building with poor indoor environmental quality, is this a term you are familiar, and as a building occupant are you able or willing to describe what you believe this term means.*

9. *Again and as a building occupant, are you familiar with the term Indoor Air Quality. If you were to attempt to describe what this means how would you describe such a term and the salient points in delivering acceptable air quality.*

10. *In your opinion what are the most important aspects a workplace environment should deliver in satisfying the expectation of the occupant in order to create a general sense of personal well-being and to drive personal performance and/or levels of personal satisfaction. Do you believe your organisation is delivering to these expectations?*

All interviews were timed and completed within 45-mins and were audio recorded and later transcribed. A sample transcription is provided with Appendix D.

4.2.1 Clean Fresh Air (Q1)

Architect 1 – *"It's important to invest, but it needs to be specific to the building, location and local issues as well as the occupant needs. Not so much wants, more economically what can be achieved to satisfy basic needs. One of the most interesting things for me anyway, is that I park at the back of Piccadilly and then walk to the office in about 5 mins. In that 5 min walk you pick up all the street pollution, restaurant smells and general city smell but what I have noticed, is that when I get into the office and we are on level 4 here, is that the smells have gone. However, we then get a different set of smells from the bakery next door and the pub in the afternoon at the back of the building. It's worse seasonally as we have the windows either open and suffer from external smells or closed and suffer from internal kitchen smells and odours. We certainly do notice a difference and that's the most noticeable difference I can sense.*

Architect 2 - "*Yes I think it is important to provide naturally ventilated fresh air and I think you can notice the difference between HVAC and NV workplaces. I have worked previously in a/c buildings and I can notice a distinct difference between discretely controlled environments.*

Architect 3 - *"I think yes, because if I focus on really thinking about it, it's a day to day aspect that is a subjective element we don't generally give any thought to, unless there is something very unexpected or out of the ordinary such as fumes or smells. Our own approach to natural ventilation, suggests that we are satisfied with the general levels of clean fresh air, however, we need to take this into a context relative to the location, such that if we are in a city centre environment we may wish to increase the investment in filtration, but that still allows us to offer some natural ventilation.*

Architect 4 - *"in my opinion it never comes on to the agenda in terms of clean fresh air it seems to be accepted as a given. I have worked on 5-6 recent office environments and all of them have been developed as naturally ventilated buildings for one reason or another, but generally because we articulate the virtues of adopting natural ventilation. This is not just from a cost saving advantage, but also as a sensible approach to meeting business needs and occupant comfort. As a practice we promote NV buildings, but we don't look to enhance the fresh air using mixed mode or increased filtration equipment.*

Architect 5 – *"Because we are on level 4 you can certainly tell the difference between coming to work at street level and the office environment, but that is probably as a function of the floor level we occupy. We do occasionally get odours from the pub/restaurant at the rear of the building, but that is generally in the summer when we have all the windows open. We sometimes also smell tobacco smoke in the summer as a result of the pub at the rear but that is when everyone is standing outside. I haven't noticed any issue from people complaining about the air quality since we have been here, other than the occasional odours as mentioned."*

Engineer 1 – *"I find and would suggest that we are under funding good air quality when you see what is available in providing better ventilation system and air management. I would prefer to use the term air management than air quality, what is quality unless you can measure and benchmark the constituent parts, and so define what quality is. Ventilated air is a product of treatment inclusive of filtration, UV and humidity, and therefore it needs to be managed. We measure and control temperature but we don't do the same for air. In my opinion we need more investment in measurement and management of the air so we can define what is a quality ventilated environment."*

Engineer 2 – *"I think fresh air is the key. NV buildings are my background particularly schools. Its essential to have clean fresh air, and for me its about CO2 levels and providing adequate quantities of clean fresh air, albeit in a NV building its hard to distinguish what clean fresh air is. The value associated with having clean fresh air in my opinion cannot be quantified, not directly. We have the internal air quality set and created by the occupants, and then we have the outside fresh air as it is presented into the space. I don't think we spend enough time designing ventilation systems, and certainly we don't allocate enough design budget to achieve a "best possible" level of air quality."*

Engineer 3 – *"I certainly appreciate the investment, I can tell when there is stale air in the room and everyone hates stale air. I feel more alert when I know its fresh air, but I do notice when it's too cold being blown into the space from the ventilation grilles. I also notice when it's too humid within the space and the air becomes stale and heavy. If it's too stale I tend to fall asleep or find space where it's fresher or leave the building for a while. We can't open the windows, so we rely on the HVAC system to provide us with good quality fresh air. Can I tell the difference between outside and inside treated air; not really, it's not something I have ever considered. If I was in an NV building then I would certainly not notice any difference, but then I would if all the windows were closed and it was full of people breathing. NV designs need to focus* *on this I think whereas AC buildings mechanically vent with the windows open or closed."*

Engineer 4 - *"Indeed yes the investment in providing clean fresh air is vital. Unfortunately the investment differs dramatically project-by-project so we never seem to see a consistent approach. In fact many of the regulations and guidance we have throughout our industry is not joined up, so sometimes it's difficult to maintain a common standard that meets everyone's expectations. The health & well-being of building occupants is affected by the quality of the fresh air delivered into the space, and I suppose it relies on the awareness of the tenant to specify any enhancements to the base build design to provide better fresh air quality. The problem probably lies with end-user occupiers not clearly understanding how the investment works and what benefits they may receive."*

Engineer 5 - *"Yes…so the importance of investment I think is important, but it's very rarely itemised in the design budget. Sometimes it's clear in the operational budget as elements need to be placed periodically, but we don't seem to cost allocate during the design process. To be honest I don't notice any tangible difference between the air externally and internally, I suppose I just accept it. I do however notice the difference when I have been on an plane, my contact lenses dry out which I have put down to the dry environment provided by the cabin air-conditioning, so I do notice it there. I don't even pay attention to the fumes and smells externally, but I do occasionally internally, but only if someone has been microwaving some food for example."*

Researcher 1 - *"I can certainly determine a difference which is not a subjective sense by the way and I can certainly see a value in providing clean fresh air into a building no matter what type of ventilation strategy it may have adopted. I think firms are investing sufficiently presently, but would suggest that most FM's do not understand or show enough interest in air quality and are more interested in what is presented via the BMS and easily measureable. If its not measured we can's respond.* CO_2 *is a good example were many buildings do not sense* CO_2 *levels or integrate this to the BMS."*

Researcher 2 - *"Yes particularly in the mornings and particularly on a Monday morning the air seems stale, which is probably due to the lack of air movement over the weekend and all the windows being closed. What is fresh air, is it like a fresh pint of milk or bread does it have a best before date, I'm not sure we have true definition of what fresh air is."*

Researcher 3 - *There is definitely an air quality difference seasonally due to the fact of the external conditions and particularly in the winter when we have all the windows* *closed. You can definitely sense a stuffy stale and almost dead environment in the winter and seasonal change periods, but not summer it's just hot when it's hot"*

Researcher 4 - *"I use to work in a building with full HVAC and I would notice that the air appeared much more fresh within the building. Here at BSRIA as a NV building, I don't notice any difference between outside and inside air, but that is probably normal for a NV building I would suggest. First thing in the morning I don't see any difference or any problems with the fresh air in the building, but I do know of others who have made comments around the winter time."*

Maintenance 1 - *"The industry knows it is under investing and we are no different if you look at what we have in this office, but that's only because we don't feel as we need anymore than this. There are no hard regulations for fresh air that I know of, but there is a lot of guidance out there to follow. How much of this do you need to follow best practice I suppose and nothing more. I have to say I take absolutely no notice to the air quality at home, outside or in the office, but I do I suppose, respond to smells. What is fresh air anyways if its treated how can it be fresh and does it have a shelf life, there's a question for you. But no I can't tell the difference it's a bit invisible I find."*

Maintenance 2 - "*In our office we don't invest too much as we are a service organisation on tight margins, however, the service we offer our customers focuses upon providing the best levels of fresh air possible, either through static filter technology or active ultra violet technology. So yes I can appreciate the benefits of investing in providing clean fresh air, it is fundamental to occupant satisfaction and performance - it filters other important elements like particulates."*

Maintenance 3 - *"Interesting question not sure I have ever given it a thought. I don't think I can too be honest I would need some equipment I think to make it real. As a HVAC engineer I am probably to accustom to the environment as because I know about providing clean fresh air I suppose I am oblivious to it unless it is particularly bad I would say. Don't get me wrong I think its very important, and we should invest in improving filters and cleaning technology, it's just that know one wants to make further investment because in my mind they tangibly can't see the benefits or even visualise it."*

Maintenance 4 – *"we should invest more as it's one of those silent issues. You can't touch it or see, but you can smell it, and that's not always providing you a safeguard. Good clean fresh air should be a pre-requisite, but we don't measure it or monitor it, so what and how do we define clean fresh air. We must invest in measuring and monitoring."*

Maintenance 4 – *"I suppose I do notice the difference if I really think about it, but when I'm at work, I tend to switch off because I'm working, but that's unless it starts to impact me. Our clients don't seem to invest enough in my opinion particularly when you think what technology is now available to provide better quality fresh air, but that is something we are trying hard to reverse, after all we ventilate for people not just the building."*

4.2.2 Inclusive Day-lighting and Artificial Lighting (Q2)

Architect 1 – *"I think both should be mutually inclusive, but it's the colour temperature of the artificial lighting which needs to be right. Daylight has a specific light spectrum, but chasing energy efficiency instead of colour rendering in my opinion restricts commercial lighting. Our lights are on dimmers and we don't have them at 100% even in winter such is the ability to accept daylight into the space. However winter afternoons are and can be dark which is when we perhaps we do increase the lighting levels."*

Architect 2 – *"We really like the lighting system as it is very functional, with centralised dimming controls to allow us to increase or reduce the lighting level. The day-lighting provision is very good in the summer and quite good in the winter despite the low level of the sun with short afternoons. We tend to use the dimming controls more in the winter than the summer as we tend to have the lights off in the main area during the summer, such is the daylight level. We do however, suffer from external glare on occasions, but we now have blinds fitted to allow us to have some manual shading control. This also helps to keep the space cooler. I think that day-lighting and internal lighting should be controlled together and automatically, but the systems need to be able to react to what people need rather than what someone has programmed into the system"*

Architect 3 – *"It's good to have access to good quality daylight which is measured and controlled, and I do think it should be mutually connected to the artificial lighting system to enable the environment to be controlled. Controlling the levels without too much change in lighting levels or contrast is important, as I think we see this as a distraction similar to when we see clouds pass over-head. Without constant light levels we can be distracted and without the desired or necessary lighting level the task can become difficult. Colour rendering is extremely important particularly when combining daylight and artificial lighting there is still a difference in colour between the two and we need more white light rather than yellow."*

Architect 4 - *"We tend to view lighting as a key workplace factor as it has such an impact within the space. The impact of poor lighting is well known, poor glare control,* *colour rendering and flicker can produce very poor workplaces and will certainly affect performance and well-being. Personally I would like to see an inclusive approach so we have energy saving, but then we focus on providing lighting that stimulates creativeness and productivity while creating ambiance"*

Architect 5 - *"Natural day-light is certainly better than artificial lighting in my opinion, but there is always a need for task lighting particularly as you age I feel. Our subjective response to day-light is embedded in our natural existence so why don't we take more advantage of this fact. The lighting within The Hive building is not day-light linked, but it is dimmable. I would like to see some day-lighting linking particularly here in Manchester, particularly when we see a lot of contrasting and changing light levels due to passing clouds throughout the day. The windows are designed for better day-light penetration within The Hive and we were specific to maximise day-light entering the space, conscious we needed to meet building regulations and best performance of the façade from a thermal perspective."*

Engineer 1 – *"The lighting here I would say is adequate, but it's a bit bland in its appearance. It's a typical Cat A fit out scheme with no interesting features, very functional. We don't have the lighting integrated with the external daylight, but we do operate the manual window blinds as we suffer form glare in the mornings and winter afternoons. I like the warm colour rendering of the lamps as the whiter lights always make me feel cold. We do suffer from some glare from the ceiling lights as we have white reflective desk surfaces so it can be an issue later in the day when your eyes are tired from all the VDU work. Not sure that mutual control would really benefit most spaces as the daylight contribution tends to be around the perimeter so the control would only help those around the perimeter, and in any event, we cannot control the daylight level as its considerably higher than anything we can produce internally. I think façade glare control and improving the artificial lighting is where we should focus particularly around colour appearance, uniformity and by creating an interestingly lit space to stimulate the occupant. LED lighting and changing how we say internal spaces to create artificial daylight is where I would like to see us heading."*

Engineer 2 – *"I think the internal lighting should be controlled with the external lighting in some way for sure, but what's important is keeping the lighting levels well controlled and uniform across the space. This is more difficult with deep workplaces, but we should always consider the uniformity of the light levels wherever possible. Day lighting could be controlled better, but this requires control provided at the façade through intelligent glazing systems, window blinds, external louvres or perhaps even building orientation."*

Engineer 3 – *"We tend not to control the daylight through the façade, but we do have a go at controlling the artificial lighting by dimming it to off. Seems to me we are not really answering the question, merely trying to save energy. Colour rendering, light quality and matching daylight and artificial colours is important to me, and with LED lighting we now have more options in terms of creating similar colours to match daylight. This is where I think we should be focussing our efforts, getting the colours to align then control daylight to maximise its benefits, however, we need the architect to get this to work better. If we could achieve one environment where daylight and artificial light colour rendering and appearance was the same, then I think it would be a great benefit in creating one environment."*

Engineer 4 – *"Because I am next to the window the light quality is excellent. We've only been in this office a few months, so it will be interesting to see how it looks and feels in winter when its dark at 16:00 and we rely wholly on the artificial lighting. Perimeter dimming seems spasmodic and erratic so that's annoying. The lighting itself is of good quality, uniform and its adequate for me, it does a good job. The colour is good and I don't suffer from any glare from the artificial lighting, but occasionally I do from the external lighting until I adjust the blinds. To answer your question I think we should control the external and internal lighting together, but in what discrete manner I'm unsure."*

Engineer 5 – "We *have possibly too much daylight given the buildings orientation, so we do suffer a lot from external daylight glare. In the summer and possibly this winter, we will have the blinds down quite a lot, but that then detracts from being able to take in the external vistas. The space takes on a different perspective with the blinds down, we lose the views and it feels as if we are in a box to which the artificial lighting struggles to make interesting. How we would mutually control, I'm not sure I think some real practical issues exist, we can't really control the daylight just the shading, glare and its direction so an affordable solution not sure. Colour rendering and quality I do notice, it's a bit on the yellow side and I prefer crisp white light more akin to daylight."*

Researcher 1 – *"Yes I do believe day-lighting should be used within a mutual control strategy. Within these BSRIA buildings, we do not do enough to provide good lighting, but we do have considerable daylight, but this has its own issues. Day-lighting provides a better visual environment rather than artificial lighting in my opinion and should be utilised more but with better glare control somehow"*

Researcher 2 – *"Here because we have a lot of glazing and where I sit, we can go a lot of the day and year without artificial lighting due to the high proportion of glazing. When we do use the artificial lighting, which is more during winter afternoons but also* *in the mornings, I think it could be significantly improved. The old light fittings and lamps could be improved with a better quality of light. We accept the existing lighting because we rarely use it as I mentioned earlier. Should they be linked I think yes from an energy efficiency perspective, but also we need to be more astute in how we control the space. We have excellent daylight but we do suffer with glare in the summer and in winter when the sun is lower. How we link this to the artificial lighting I am not sure, but light levels should be linked automatically, but we need to be able to override when working on detail, perhaps some task lighting might solve this issue."*

Researcher 3 - *"Our lighting systems range from a 1980/90's design to a the latest LED technology, but were we are using the areas that have the LED lighting to establish performance from an energy saving perspective. With the extent of window area being almost 40% of the east and west façade we have a very large contribution of daylight all year round. The biggest issue we have is thermal gain from the sun and the screen glare due to the orientation of the desks."*

Researcher 4 – *"I don't even turn the lights on in the summer so energy efficiency is a clear winner here. In terms of control, we had at my last office, windows blinds and daylight sensors, but what happened was that the blinds came down or were adjusted, and then they conflicted with the day-light sensors, so the lights were always on. In short yes I think they should be mutually controlled but with override facilities"*

Maintenance 1 – *"again I don't take too much notice of it, it gives a good level of illumination and uniformity, but the colour could be a bit whiter for me. The lighting is not daylight linked why would you other than for energy saving, the day light level far exceeds any guidelines generally, 500 lux against 50,000 lux is irrelevant. I don't think it provides any benefit to the occupant otherwise every office would have it, but then, you are only benefiting those on the perimeter. If we could get internal lighting to the same colour as daylight, then we have progress I think."*

Maintenance 2 – *"I do think daylight and artificial lighting should be controlled together, however the actual benefits tend not to be towards the occupant experience in my opinion, but more towards energy saving. Colour rendering is the key for me, and with the correct lighting level for the work task, the whole environment changes as a result of the artificial lighting. If we could achieve a similar colour rendering as natural daylight for instance using artificial type lighting, perhaps LED's have the controllability, then we have some real opportunities to create some great environments."*

Maintenance 3 – *"Colour is an issue seems to be worst in winter as it doesn't have a daylight element, but on the whole it does the job with no impact to me. The daylight* *on the other hand does give us some problems, it is so intense some-days, causing thermal increase and glare, so it's probably not about controlling artificial lighting, it's about how do we control daylight. I prefer daylight as it has a better diffuse light and colour, colours look more real, so when I am choosing a RAL colour for instance I go outside. So…. controlling both, yes, for energy efficiency, for occupant benefit no, don't see the real connection given the different colour rendering, and how the light works and is distributed within the space."*

Maintenance 4 – *"Colour is a good indication of good lighting, as is uniformity, having the right light colour to enhance or contrast with the workplace makes a huge difference. Control, well, if it's a big office then daylight linking is probably a good idea, it saves money and energy, but other than that why would you. How can we control artificial lighting that is man-made to daylight which is a different colour intensity and level, way above what we produce internally. So in answer to your question, no I don't think they should be controlled together, I think they should be mutually exclusive, but yes still controlled."*

Maintenance 5 – *"We have installed and maintain many lighting systems, and many which use daylight linking technology, but it's primarily designed and operated to achieve energy savings and never in my opinion to the benefit of the person within the office. I do however think the energy savings aspects are important, but its limited to the perimeter generally, and they are generally not that responsive. We therefore get bright sunlight and cloud and the lighting systems don't react quick enough, so most take an energy saving perspective, I've not seen any other approach. The external daylight has a considerably higher average light level, and we can't directly control that, what we need is artificial lighting which is the same colour rendering and diffuse and perhaps use intelligent glass to control the light level entering the building."*

4.2.3 Integrating Thermal Comfort (Q3)

Architect 1 - *"The problem as I see it, is that if you give occupants too much direct control they will conflict with others within a given area, either directly or through the supporting services or systems that support them. Local occupant control will work if you give them local environmental systems, but that's cost prohibitive unless you provide a NV environment, but even then I would only provide some form of local simple manual control. Most environments today are designed to a standard ASHRAE or CIBSE guideline, but we tend not to dress for the conditions, using layers that can be removed or added is a good option I think. If we could educate more, that may help energy efficiency and help with the conflict issue."*

Architect 2 - *"It's quite stuffy in the morning then we ask the engineers to open the vents via the BMS as soon as we come in at about 08:00. Its difficult to please all the people as they all have different needs and requirements, but the one thing that could help, is if the vents where more intelligent to open automatically and to react to the actual environmental conditions. We have operable windows which help, as we can manually make an intervention, but this is always reactionary rather than a pre-emptive step. I don't think automating the window is an answer, as people seem to like to have that psychological affect of making a change by opening the window."*

Architect 3 - *"Yes I do must definitely, but I am not sure about the level of intelligence required. I think there is a real connection between your senses and taking an action to alleviate a problem such as opening a window for instance. Direct control seems a good idea but we still need the occupant to interface. The level of intelligence is perhaps a concern as the systems which need to integrate in the background need to be robust otherwise you will create even more problems and then not satisfy the occupant in any way. Technology is great, but if the FM can's see it, understand or fix it quickly you have a host of other problems."*

Architect 4 - *"From our sustainable agenda, thermal comfort is key success factor and we strive with the services consultant to design spaces based upon suitably tested models. I don't believe it's a case of occupant control, its about intervention and systems integrating and reacting with the user. Yes, we should see buildings which learn, but the building is just an object, the intelligence comes from having buildings which use occupants as agents and can act as sensors or take control subject to the design of the workplace being right."*

Architect 5 - *"The trouble I think we have is that we have working environments that are different every day. The workforce to day is agile and therefore not all desks are full everyday or even at specific times of the day. The related issue here, is that we generally design to a standard which is 100% occupied so is not a sustainable or efficient approach. This agility factor we are now experiencing is affecting all aspects of buildings not just thermal comfort. Personally, I think it's about air movement, rather than temperature, which is why we believe naturally ventilated space work better than engineered forced cooled or heated buildings. Once it gets too hot, then we should look to adapt to the environment instead of asking the building to react though some form of BMS.*

Engineer 1 – *"Systems that work intelligently and learn are a must, but they need to work by predicting means based upon historical measured data and user input requirements. Some control is a necessity, but I think it needs to be automated such that the occupant can interact but with the system having ultimate control."*

Engineer 2 – *"to an extent I would agree with the question, I do think we should provide more occupant control with the HVAC system learning from historical performance feedback both daily and seasonally. Why would we not want to do this, it seems quite logical. The only issues I see are the level of control available across different requirements. Yes we can introduce algorithms and averaging calculations, but what we are doing is creating more complexity while still not solving the problem. I'm not saying we need to design to an individual level, that will be too costly in all sorts of ways environmentally, but what we can do is design the workplace to have different areas where people can adapt to different environmental levels and control philosophies – perhaps!."*

Engineer 3 – *"That will never work, I used to work in FM and any person in a group of 10 will want a different environment so we will always get systems confused and failing as they attempt to deliver to everyone's expectations. We as designers are constrained by budgets so we can only provide a certain amount of control within any budget. Todays BMS systems are also not intelligent or robust enough so we have interoperability problems. I'm thinking occupant to BMS – to the HVAC system and potentially back to the occupant, you would need an IT system and completely different software architectures. Seems we would be over complicating the building and for it to become so intelligent it fails."*

Engineer 4 – *"It's really down to intelligence in use I think. Typically on a BMS system you may offer some manual operation but it needs to be managed by the BMS. We will never satisfy everyone all the time. For HVAC systems, air distribution is key and this is where we see most issues. The 2nd part of your question, systems that learn intelligent, I think is very important, but current BMS systems are not intelligent enough to integrate and operate at this level so some real work to be done here by the BMS OEM's."*

Engineer 5 – *"It's funny, I work from home a lot and my home office/study is much hotter than the office here, but I accept it and adapt. Strange don't you think, we accept one thing at home, but expect more when we come into the office."*

Researcher 1 - *"There is so much variation between people that you cannot satisfy all the people all the time and compromises need to be made. When we design systems we tend to design zones too big, we therefore need to look at providing individual control or some other form of granular intervention to the occupant conscious that the variation exists. I don't believe we have our thresholds right for thermal comfort even now, and I think we need more individual environments to satisfy occupants and reduce energy usage"*

Researcher 2 - *"Similarly to the lighting system there are complications when so many individuals are involved in sending signals. I see many conflicts occurring which even with an intelligent system I am not sure todays BMS or lighting system will cope. The fundamental issue in my opinion, is how do we satisfy the many unless they have individual environments at the workplace, or does the workplace need to fundamentally change as we are seeing with hot desking and agile working. The different transitionary environments are now becoming the norm and we are not in one place all the time so do we need extensive BMS and HVAC systems I don't have one at home. It's a window opener, a single thermostat, timers, light switches and some TRV valves, but they all have one thing in common a simple personal interface me"*

Researcher 3 – *"Its hard work trying to keep everyone satisfied all the time. I have noticed that females seem to be human sensors and can tell the differences between temperatures in different areas such that when I check the temperature they are invariably correct."*

Researcher 4 – *"I think it's difficult within open plan offices as it's an individual thing. Not just gender difference, but age and background comes into play. Individual characteristics will dictate differences and different responses, so we would probably need some form of democratic response and decision making within the building controls. I suppose it would good to have some sort of feedback to the facilities manager at least, but my concern is the intelligence within the building controls and them being able to sufficiently differentiate accurately and consistently across multiple agents within the same space. A feedback loop would be a useful to enable aggregated data to be fed back to the occupant, this would provide as to why the temperature or the environment is performing as it is. I think this would be a very useful response to placate people who are frustrated, a sort of democratic decision making and convergence of being"*

Maintenance 1 - *"Good question…..I would say no to control, but yes to some form of learning, providing it doesn't over complicate the BMS systems, they are fickle enough as it is. We find building users or occupants as you call them, want feedback, whether its personal or via an email to say their complaint is being or has been actioned. If there was some way to provide direct automated feedback that would certainly help the Helpdesk issue."*

Maintenance 2 - *"We see this constantly in our day to day delivery of building engineering FM services, it's our biggest headache. Some degree of intelligent learning would be good, but we have such a diverse industry with many protocols I'm not sure we can make this work without some standardisation within the controls* *packages used. Direct occupant control depends upon the installed systems and their extent of coverage across a floor plate, giving everyone control will need some averaging controls and feedback otherwise it could get a little chaotic and frantic stressing the occupants even more. We need to be very careful in how much control we offer users."*

Maintenance 3 – *"Direct user control definitely not, the ability of even todays BMS systems to handle data is poor, giving them multiple inputs would need a complete re-think of how we interact with buildings. I think we should give feedback to the user on how the building and the relevant areas are maintaining set parameters, but that's it. Nothing elaborate a simplified version of the BMS system. To learn intelligently yes, I think some element of artificial intelligence would be very useful based upon trending and data analysis. Linking user requests, HVAC systems and building performance would be a great idea, and then calculate an adjustment and then feedback to the user would be a good step."*

Maintenance 4 – *"Yes I do in terms of intelligent learning then using algorithms we predict future user requirements somehow. The problem is the control functionality though, again why do we want it. Let's look at want users want or need, then get the building to interact and feedback what it's doing rather, than getting multiple users to try and control it. If the building could sense my needs wouldn't that be good, then all I need to know is that the building is working to achieve those needs….brilliant. Don't think I need to say anymore, that's what we need I think, but we don't have it yet."*

Maintenance 5 – *"Yes and No is the simple on the fence answer. I think we are getting better designs now and people are seeing a connection from home to the office, but the workplace needs to be commissioned and maintained properly if we are to provide an average performance across thermal comfort. We have direct occupant control at various levels now, but I suppose you are inferring about autonomous user interfaces and for the local area they occupy. This is difficult with so many different user requirements. Rather than give direct control, I think it would be better to have direct user feedback, and by that I mean the building reacting to set preferences and then telling the user of the space how it is performing to achieve those preferences."*

4.2.4 Intelligent Building Controls (Q4)

Architect 1 – *"I'm not sure what the real advantage would be. Seeing the Hive Home Controls for your home heating – have we not gone too far with APPs, why control things remotely at home what happens when it doesn't work or there is an issue with the system. There needs to be a consensus of thinking. First, a protocol and a vision to what is the ideal level of control and second some form of user occupant feedback strategy. BMS are not intelligent enough at the moment, until they change let's keep it simple."*

Architect 2 – *"We have manual control over all other systems lighting, window vents and heating to our area only, but that is all we need providing the central systems are operating as timed."*

Architect 3 – *"As I said earlier not sure technology is the real answer. I'm a bit of Luddite when it comes to control philosophy, I like the keep it simple approach with manual intervention within the design and operation of the building. I like the idea of the integration through technology, but it's what level of intelligence do we actually need to satisfy what occupants actually want."*

Architect 4 – *"Lighting, temperature and ventilation are relative to what occupants can have active control over. They cannot control humidity directly or the air quality, so we seem to be constrained to controlling the basics when perhaps we should consider the total aspects of workplace systems. If occupants respond to workplace factors, then we need to give them total control. The dilemma however is to achieve this for everyone and to avoid the conflict between different users. BMS are not yet intelligent enough to deal with such data requirements nor do they seem to have sufficient sensors or coverage. I wonder what would happen if we lost all aspects of intervention would we have resilient spaces that are reliable or spaces that become over complicated and unusable. Technology is great but rubbish when it doesn't work, everything stops."*

Architect 5 – *"Today, and if we were going to provide a system interface, then I think it needs to be phone or ICT App based, this is what people are becoming more familiar with and seem to want. There will however in my opinion be an issue with people adjacency and some level of conflict, but we just need to educate people to communicate and to manage themselves within the workplace. It's not just about building physics to solve the environmental problem, it's about people learning how to interact with their local environment. What we need in my opinion s something akin to the luxury car where you set the parameters you like and tend to feel comfortable, the you have an interface were you can adjust if required. Designers need to focus on what's important and not to over complicate the options you have to control* *things. When a building is occupied people should respond and integrate with the building and the building and the user should control the environment. When the building is empty then the building systems should simply react to achieve a prescribed set condition and then close everything down to save energy. Buildings need to learn when the building is just a building."*

Engineer 1 – *"I don't think its good idea for direct occupant control, we should let the building control to its optimum design parameters. For intelligent controls, the building needs to learn daily and seasonally then somehow calculate the best optimum performance to suit the occupant requirements. So I suppose their needs to be some control interface, but perhaps it's more of an advisory nature to the occupant and for the BMS to acquire data to correlate the environment to user expectations. A sort of pseudo control and feedback scenario, but I don't know how we will achieve that with todays BMS systems."*

Engineer 2 – *"I don't think we should transcend to the individual as I mentioned earlier, what I think we should have is better functional environmental monitoring and control. Coupled with different areas and systems to create different environments, I think we should learn to naturally adapt to our environment with control only being released when it reaches pre-defined limits. The building should feedback to the end-user with the end-user being alerted to make an intervention rather than simply waiting for the environment to create an issue that then impacts individual performance."*

Engineer 3 – *"Personally I would like to be able to control the lighting around me in terms of colour, intensity and lighting level, and I would like to able to control the temperature, but that's a personal view and not my FM view. If I give 500 people say control of the lighting and temperature in a building today, the systems would probably crash and then productivity would be impacted as a consequence of the designer over complicating the buildings control system. Our clients would not be thanking us for that."*

Engineer 4 – *"Yes I would like to see more controls being offered to the occupant, but it depends on what we want to control to improve the environment for the user and not to make it worse. What are the available user interfaces, a communal portal to just view how the systems are performing would help or even individual portals at each desk so each user could see how the systems work and are performing might be good."*

Engineer 5 – *"Not sure that we need too much more direct control, but feedback would be very useful to give the occupant some integration with the building. Each building system is different and has many options, so you would need to have* *specific integration per building design, and you couldn't just have an App that automatically connects – not yet anyway. There are too many variables and people are all different and BMS systems are not clever enough or resilient, so we could be causing other operational problems by trying to be too clever."*

Researcher 1 - *"I think it could be a good thing to provide individuals with influence on there own zone, but I don't think it will work practically and therefore people would become more dissatisfied. The illusion of having some control in what ever form would perhaps be a better state than no control at all. Too many users having different real time requirements will be very difficult to measure calculate and react."*

Researcher 2 - *"I think it's a step before that and before we move to being fully integrated to the building. What I don't see is any building feedback coming back to me, or the building users. I think it would be very useful for users to be educated by what is going on within their workspaces e.g. lighting, temperature, humidity and importantly CO2 levels, 3-core issues which fundamentally come towards the top of many feedback surveys. f we can satisfy these 3 issues by showing how the system works and provide real time data this would be a very valuable first step and as part of any future control integration. Back to my previous control points, we need to make sure we satisfy everyone and that systems are robust enough to handle many stakeholders wanting different settings."*

Researcher 3 – *"In terms of an interface I would probably say through the PC as not everyone in the office has a new modern iPhone, we have a high age group currently and so not everyone would then have the same functionality"*

Researcher 4 –*"I think we should look further than just iPhones, perhaps it's a pill or a inserted capsule or some sort of sensory exchange device. But perhaps it's an app but were I think the request should go to a person before it's sent to the building system to act. I don't see that a psychological response is going to be achievable, but I do see empirically measured data being transmitted by a device to enable the systems to respond directly. We also need to be conscious that we need to interact with things, so we don't want to become oblivious to our surroundings, its about experiencing things that makes us human"*

Maintenance 1 – *"You don't complain if its too hot anywhere else you just get with things. If its really bad yes complain, but perhaps that's what should be automated the complaint process and eradicate the helpdesk, there, there's another idea for you. Automate the Helpdesk, fix the problem then auto respond to the user. That's intelligent FM."*

Maintenance 2 – *"As an engineer I would like to have more control as I understand the systems and how the work behind the scenes, I am not sure it's at all sensible* *providing control to folks who don't understand how the systems work. It would need a very simple user interface with pre-defined limits of adjustment and with some feedback to the users. It may be better to have occupant preferences sent to the BMS systems, then the BMS system feeds back to the occupant that its doing its best to achieve those preferences – what that looks like I have no idea currently but I think the principle works."*

Maintenance 3 – *"As I said No….let's keep the user focused on the work tasks and let's agree a set of parameters perhaps from a voting systems that the systems then control too. Feedback to the user is the key, let them know what is going on. For this interface to happen though, we will need a comms protocol that fits every building and BMS system, a sort of common platform I suppose. Each building being different will present a challenge, as there are so many access devices and protocols. People just want to get on with their jobs don't they, and not be faffing with the building systems."*

Maintenance 4 – *"Again yes, but only those that make sense. Trying to get modern BMS to control anything is bad enough, let alone having a 1000 people plugged into it. Keep the intelligent control simple, think about the workplace itself what functional controls would you like to see delivered. I would allow access to system feedback but not control."*

Maintenance 5 – *"Yes there are some things that should be given more control. I think the occupant should be able to control how they efficiently exist within the space, and by that I mean workplace issues not technical systems that service them. By this I mean desks, ICT, movement, Audio Visual systems, room bookings lunch orders, the softer side of how we occupy buildings. As work practices change, buildings will become transit spaces only occupied for short times, so the technical factors in my opinion will soon become irrelevant. I think the way forward is for preferences to be indicated and for the building systems to feedback how they are performing in a common language."*

4.2.5 Workplace Standards and Inter-Operability (Q5)

Architect 1 – *"Branding seems the driving force in my opinion, but this seldom translates into a common set of engineering or architectural set of standards and demographics play a big part, so common standards may not always work."*

Architect 2 – "*Our offices are very similar with the same minimalistic feel and use the same workplace arrangements, ICT desk supplier, lighting and controls philosophy. The only difference with the London office is that it is much older and* *does not have the advantage of a more modern naturally ventilated design. The directors have taken the initiative to try and provide a similar feel for when we move between offices, but that was also from of a cost effective and sustainable approach to our fit-outs as well as towards reducing operating costs."*

Architect 3 – *"Yes I think it is important we have a simple look and feel to the workplace, but we will always be constrained by the building. Culture plays a real part, and the organisations culture sets the view of buildings. The branded workplace then becomes important. Our brand identity is set by our designs and how we operate from here. Strategically we should have a set of guidelines not standards and each project then sets its own standard within an IEQ framework. Energy standards will remain an important factor for example, but the workplace can have its own guidance and over arching standards specific to each organisation - that's the future."*

Architect 4 – *"we are making an attempt to make the workplace similar in look and feel. It's not particularly that we want an identical office, but we have clients that use and visit both offices, so we want our brand to be consistent across our offices."*

Architect 5 – *"Yes I do, and I think it's even more important when you have multiple offices where you could have different assets and systems that need to interact. There needs be some consistency, but some personalisation particularly when you move between offices. Something that is familiar is always reassuring as you feel more comfortable at home within the space more quickly. Meeting the needs of the occupant by making the workplaces similar to work within, operate and enjoy is a key factor we adopt when designing buildings or workplaces. We do however need to be careful when defining a standard. Europe and the UK has such differing demographics so within the UK its fine, once you move internationally other demographic issues come into play, so we need to be careful when we standardise. The difference in external temperatures across the UK can be extreme, yet we still design to a common standard. We seem to be using the wrong criteria in my opinion setting internal temperatures as the standard. If we are going to be sustainable then we need to set our designs based upon external temperatures with an association towards what the occupant in a specific regions can realistically adapt to or tolerate."*

Engineer 1 – *"Not really a primary consideration in my mind, but what I would like to see is some contrast within the space, more importantly though some colour. The drabness of a grey workplace makes it very clinical, and psychologically it impacts my general feeling of well-being."*

Engineer 2 – *"Well probably, but its not something I would say is a necessity. It may have a financial benefit in normalising design and workplaces, but not sure it needs* *to be replicated. I think having different work environments helps to stimulate you, working in different offices provides an option for the occupant to consider"*

Engineer 3 – *A consistent set of standards yes in terms of the basic HVAC and lighting systems etc., but certain elements should be more tailored around the work task and direct occupant comfort. Having the same overall workplace strategy I would agree with, but what serves these spaces can be different for a host of commercial and practical reasons."*

Engineer 4 – *"We didn't design this office, it works across an average of satisfying a level of basic requirements against existing standards. So having a same feel every where we go may actually cost more, so it's a message of what best fits I think while satisfying the majority of business requirements."*

Engineer 5 – *"I wouldn't say this is at all important, we need to look at each building specifically and design accordingly to suit the buildings characteristics. The overall look, feel, work arrangements and layout yes, I think this would be a good idea to provide some familiarity and comfort factor, but its not that important. What's important is that the space works to get the task completed and the services that support it are working to provide similar comfort ranges."*

Researcher 1 - *"We would probably always recommend such an approach to others simply for economies of scale, ease of maintenance and energy consumption by selecting best in class equipment. I think that other building users should have the same interface in whatever building they are working, the systems can be different, but the user interface should be the same to the occupant"*

Researcher 2 - *"I think this would depend upon size and other issues relative to the business occupying the buildings. Where I see a benefit is perhaps selecting a high level strategy standard but then look at individual building, task and occupant circumstances. I can see where it would be cost effective for FM teams to have a common standard, but I think if you are going to adopt say full HVAC, Mixed Mode or NV, then that is where the designs are standardised, then each building is designed accordingly."*

Researcher 3 – "*Yes we should have a common standard and approach but that is going to take a lot of money. I would like to be able to provide a common set of temperature standards and perhaps workplace standards as from my FM perspective it would allow me to respond faster and provide a better environment. Well that's what I think anyway and we have the standards to adopt on the shelf we just haven't put them into a cohesive FM document"*

Researcher 4 – *"No I don't think they should all operate the same, but I think the branding should be the same. From a workplace perspective I think they are all* *dependant upon external factors, their location the work task and the general demographic etc. Each building will be different and the weather conditions will be different in different locations."*

Maintenance 1 – *"The construction process doesn't lend itself to standardisation, neither does the economy, it would erode competition, so I think a general look and feel yes, but each building is different. Selection of specific suppliers may be a sensible step, but they sell many ranges these days, and you select for what best fits at the time. ICT and Wi-Fi for instance, having it to automatically connect is vital. It's more work orientated and space orientated for me, and not so much about the systems that support the space."*

Maintenance 2 – *"No not really for us as we only one office, however, in our experience and we tell this to our clients, that if they could standardise their assets and select against some life cycle principles, they will save not only costs and emissions, but also in delivering a better sharper service to the workplace. When you are working in any workplace, you want to take the thinking out of thinking."*

Maintenance 3 - *"Standardisation is very useful but I find many don't strategically think about what this really means. End users tend to think about the workplace branding and look rather than the engineering and workplace systems that specifically support the workplace and occupant productivity/performance."*

Maintenance 4 - *"Simply no, we are evolving into a transient world so you are not going to need such corporate views. Even in the corporates, you are now hot-desking more and working anywhere, so you are already seeing different environments, which by the way you have no control over. Meetings and working in hotel lobby's coffee shops and bars you don't have control over them. I would though, like to see this feedback idea as a consistent standard, so that where ever you where you going, you could see if it was performing to what you would like experience in a space, and even if it was crowded or noisy. A simple consistent standard sending the same message to multiple platforms, now wouldn't that be good. The individual would have a choice of where he would best make a meeting let's say."*

Maintenance 5 – *"All buildings are different and systems will need to be selected to fit various needs and characteristics. What I think would be a good idea though is if we had a common interface language between all the systems and networks, and then within the feedback principle I keep suggesting. Now that would be progress."#*

4.2.6 Occupant Satisfaction and Well-being (Q6)

Architect 1 - *"I think ICT is a key issue for performance, and ergonomics at the desk is vital. Posture at the desk is so important for me. Getting the job done is what I focus upon when I'm in the office and not the office, so perhaps we have the environment right here. The acoustics here are not perfect which can be a distraction so we have break away spaces."*

Architect 2 - *"Desks definitely, office desk location and ergonomics very important for being satisfied with your environment, good ICT, ventilation and temperature are all big issues. Specifically, thermal comfort for health and well-being to avoid absenteeism is key for us, our business doesn't function at all without healthy people sat at their desks. The general ergonomics of the space and its functionality for providing the user with a comfortable environment is vital in keeping the staff satisfied and well. We tend to keep things simple, functional but thoroughly designed to suit the majority of individual requirements."*

Architect 3 - *"it's about getting the job done within an environment that's helps you to feel productive and satisfied. Acoustics is important and having different types of environment to allow you to get quiet spaces like we have here, day-lighting and lighting in general is very important as is IAQ. For me personally it's about acoustics, noise and IAQ. Having a collaborative space is essential to keep a team sprit, so you need people who are of similar views if that makes sense."*

Architect 4 - *"Day-light is high in my opinion, noise quality is important and not just the level. It's the type of noise, its pitch, and its sharpness that I find difficult, so it's important to understand the consequence of noise within the workplace and to design an approach that meets specific criteria from the users of the space."*

Architect 5 - *"Two key things exist in this area, but there is a third, the look and feel of a space, is it well maintained and is it somewhere that you like and feel proud to work in for instance. IEQ factors are very important, but it's in the last 10-yrs anecdotally, that I see people are tending not to complain about their environment, but complain more about data and IT issues. A poor environment reflects the way organisations treat their employees, but the design needs to be representative of occupant needs and desires rather than just a designers thoughts."*

Engineer 1 – "*To be fair our interest really is in getting the job out of the door, and we feel satisfied in accomplishing a successful set of documents, its only when we talk like this that I think we actually look at the place we are working in."*

Engineer 2 – "*In terms of IEQ factors air quality has to be a my real choice for helping me to focus on my task which is what give some satisfaction. I can deal with being too hot or cold I can do something about it, but air quality I have no intervention* *measures or control apart from moving to another office so I am totally reliant upon the design being 100% right."*

Engineer 3 – "*Lighting is extremely important, it can change a space fundamentally and therefore impact the occupant both positively and negatively. Having lighting that works with the body particularly in the afternoon to stimulate the body's rhythm would be very useful, perhaps this is where we could see some automated occupant control?"*

Engineer 4 – "*Perhaps we should conduct a POE survey or something to ask staff if they have everything they need to feel satisfied in their work. I have good laptop and ICT desk equipment, and tend not to hot desk as I'm usually in early so get the same desk, I have good space surrounding me to lay things out so generally I feel very satisfied with my environment. As I mentioned earlier the systems supporting the environment, the AC, Lighting, blinds etc., are all working with me to achieve what I need. In terms of well being, I think being satisfied takes some of the stress out of life, so my well-being is good in the office. If I can't do my job, then I think my well-being would be affected, but in this case the systems and the environment are not negatively impacting me."*

Engineer 5 – *"Lighting is very important, and excessive thermal issues need to be avoided, good fresh air and thermal uniformity is also important, but having the right tools and ergonomic desk is vital for me to feel satisfied and so that I can completed the task to my best ability. Having the best ICT equipment that is always working is essential. Well-being difficult to answer, as being satisfied in my job I feel better in myself, so is that well-being, I don't know. If I'm unstressed, healthy and not ill as a consequence of my environment, then my well-being will obviously be good, its probably more about the total package of the workplace, the services and how I feel generally outside the office that satisfies my well-being. If you want me to list what I think is important for well-being, then it will generally lean towards making sure I am healthy, so no headaches, low levels of CO2, thermally stable, no drafts, fresh air all day, and no dust particles which could irritate. Coupled with a satisfaction from the work task and avoiding these issues."*

Researcher 1 – *"If I was to select any aspects, it would be about things I know about. Glare should strictly be controlled from both artificial and daylight sources. I am not so bothered about thermal comfort, but others are, CO_2 I think is the invisible important factor that should be monitored and controlled, it is so fundamental to performance particularly from the work I and others have been doing in schools. The visual impression is very important externally and internally, it creates a good feeling of being satisfied in my opinion although it is very subjective. Lighting levels is* *another issue, do people need to control there own lighting levels, my experience from many surveys is that people prefer less yet adequate light to work rather than the prescribed levels we see in many designs and therefore dimmable lighting is a usual function"*

Researcher 2 – *"for me it's a window and having a view which is interesting and not just a plain wall which we seem to have quite a lot of. Natural lighting is important and I personally like the NV approach. For well-being I think natural light is important and I love fresh air, even in winter I like the window open. I also like the connection with the outside and as you see we have some plants around the office."*

Researcher 3 – *"we are working in a 1960 and 1980's building refurbished to a 1990's standard, therefore its hard to gain a level of satisfaction, but I would say I don't see a lot of dissatisfaction , I just think people have got to use the environment and accept it for what it is. Well-being is not a term I would use at the moment, but again I don't see any major absenteeism as a result of the office environment or facilities."*

Researcher 4 – *"The first thing for me is temperature that is the most important thing for me, if I am too cold that's it for me, I just can't work and have to keep making hot drinks which is a distraction. Then I would say it is comfortable furniture and ergonomics, and then I would suggest its some quiet thinking space. I don't believe there are a set of defined expectations, so its very personal and different I think"*

Maintenance 1 – "*I suppose satisfaction is about doing the job successfully and feeling good about doing it. You need the tools to do the job, so if you have them, and all you need in terms of a good environment to work in, then I think that provides a level of satisfaction. Well-being you say, really not sure on this one, is it psychological? a state of mind, not sure. I suppose it's about, Well… a state of healthiness perhaps, and being… being generally happy don't know what do you think. All I know is, is that the building shouldn't make me ill and should provide everything I need to the job to my best ability."*

Maintenance 2 – *"Air quality and thermal comfort are without doubt the primary areas of focus we should adopt and expand upon. Lighting yes, as I have said, but each building is different and so are their occupants so we should focus on the areas which provide definite tangible returns – good air quality, thermal performance, ventilation rates and feeling, good ICT and desk layouts are also essential, but in our world we focus more on the building rather than the occupant."*

Maintenance 3 – *"Without a doubt it's about having good ICT, workspace and printers and plotters that always work. I need to get the job out the door so having the tools available 100% is key for me. The workplace environment is not important* *providing its not impacting on the tools to do my job, I can adapt to thermal problems, but I do need adequate lighting and no negative distractions. Well-being is slightly different, this is more about my physiological feeling I think, so air quality is key, not transferring germs and pollutants. Thermal comfort yes to a certain extent, but also noise, too noisy a space and you feel stressed and uncomfortable."*

Maintenance 4 – *"Satisfaction….simple, no hassle, don't even want to get in involved or notice the workplace. I'm here to do a job and that's it, that's my view. Having said that it needs to be an environment that encourages me to feel happy and interested in being there, subconsciously I think. All those usual environmental factors need to be good and the desk, chair and ICT needs to be good these I think are the key principles, but everyone is different. Having a good FM who knows how to tune-up the building is always good."*

Maintenance 5 – *"Being able to do the job to your best ability, to have a feeling of satisfaction at the end of the day, that's what does it for me. For me to feel satisfied I need to have an environment that psychological puts me at ease, but physically it works also. If you want me to think about workplace factors, then I suppose I would say, good appropriate glare free lighting is important, not too noisy and thermally acceptable, oh and ventilation which keeps me alert. As I said earlier, it does get stuffy in here sometimes and unpleasant, despite everything else being right."*

4.2.7 Noise & Vibration (Q7)

Architect 1 - *"I get very distracted when its busy, and you can hear conversations further away but not when you are on the phone for instance. The meeting rooms are also an issue as we can hear a lot of what's going-on in the room, but at least they are at the other end of the floor towards the quiet zone. Vibration is not an issue and we don't suffer at all for it."*

Architect 2 – *"There is quite a bit of noise that comes through the full height wall vents and I have been asked to close them a few times. We do have some issues with acoustics as you can hear conversations very easily across the office particularly if its not full and busy. If you are in the meeting space, you can hear what is going on outside, so we sometimes have to manage the space when particular meetings are occurring. There is no acoustic treatment to the full height fresh air vents, so outside noise does impose itself at busy times of the day, and particularly in summer when we have the windows and grilles open. We can tolerate some noise levels, but have to intervene more in the summer. All the finishes within the space are very hard surfaces so acoustically we can struggle at times."*

Architect 3 – *"Noise is a big issue with all the hard surfaces here, and I don't think we got this particularly right. We have not applied any acoustic treatment to alleviate the issue, and we have sort of accepted that it's distracting. Distractions do exist throughout the open plan area, but they are probably necessary distractions in my opinion, it enables us all to feel engaged with our surroundings and with your colleagues."*

Architect 4 – *"As I mentioned earlier noise is an issue but we use the music to alleviate some of the noise distraction. We all have a smart app to control the music, but we do have a veto button if it gets out of hand. Vibration has not been an issue in this building and I have not seen any major issues from vibration."*

Architect 5 – *"Noise and vibration non specifically, but what is noise. From my university days, noise is defined by unwanted sound that in this office is the music being played too loud or too many people on the phone when you are trying to have a private conversation. In an open plan office noise seems to be the biggest issue we suffer from but we only have a finite amount of space."*

Engineer 1 - *"I don't suffer from any noise distractions and there is no vibration in this building or on this floor. I seem to be able to tune out noise distraction and focus on my work. It's a little quiet in the mornings so it does have an awkwardness about it."*

Engineer 2 – "*We don't have any vibration issues. I have mentioned noise as being a negative issue, but conversely I need some noise to feel part of the environment. I also think certain nose that is communication noise and people interaction is needed to learn what's going on in the office and to give you some psychological engagement with your colleagues. If its too quite I wonder what is going on around me, but then if its too noisy I start to loose concentration which is when I seek a quite space. Our hot desk policy creates noise as you have the constant churn of people so that's a big issue."*

Engineer 3 – *"Vibration is not an issue, and neither is noise for me, I suppose I just tune out, but still aware of what is going on around me."*

Engineer 4 – *"Noise is not really an issue for me, I like the buzz and banter of the space and between the people within it. Timing is sometimes off though, particularly when I need to focus on something, but I tend to either move to the breakout area or jump into an empty meeting room. I certainly don't pick up any noise form the HVAC system, it's generally noise generated from the occupants and their use of the space, photocopiers, walking, talking, phone calls, discussions etc."*

Engineer 5 – *"I don't suffer from noise intrusion or vibration issues in this office its all pretty well isolated from the outside. The internal acoustics could be better as we* *have a lot of hard surfaces. The main distraction is from other people talking or on the phone, but that's a function of being at work. I just get on with it generally and take things home if I need to work on something detailed."*

Researcher 1 – *"I find office noise a major distraction. When other people are talking I find it very difficult to concentrate and tend to listen rather than being focussed, so it's a big issue for me personally. We could probably do something about this by doing some acoustic analysis and treatment but it's not considered a significant issue we just get on with things. Reverberation noise seems an issue as we have very hard surfaces throughout the office and noise can generate quickly. Perhaps acoustics is one of those issues were people ignore it. External noise is not an issue, it's the internal distractions which are worse."*

Researcher 2 – *"Noise can be an issue on the odd occasions when it is really busy, but for me it's when the office is empty or people are concentrating and there is no noise. To such an extent we went and bought a radio to provide some background noise. Where I live we live next to a train line, which you would have thought would bother me, but I have so tuned it out that I could not tell you when the last train went by. I think it's the same at work you can tune distractions out if that repetitive, it's those unexpected or different noises that distract you."*

Researcher 3 – *"We do get a lot of traffic noise as a consequence of the main Bracknell/Reading interchange outside and as a consequence of the single glazing. The summer is quite noisy as we have the windows open, cooling fans on desks, fire and ambulance station 200yds away, train tracks 100yds away, the main road and Heathrow air traffic over head so it can get quite difficult to concentrate sometimes. Its also a nice distraction if that makes sense, and what I mean here is that sometime you can isolate yourself, so its nice to hear the outside world even the birds"*

Researcher 4 – *"I don't find I am distracted that often by noise as the office is quite quiet anyway, however, we do have music in the background which helps to provide a common background for everyone, so its quite nice to have something common in the background. Traffic noise is quite bad, and sometimes people who are having conversations intrude into your personal space."*

Maintenance 1 – *"External noise yes, this is a poorly insulated and acoustically clad building it's a warehouse really, just converted to offices. Internally no real issues as have my own office and can close the door, but I spend a lot time out of the office in a noisy world so I suppose I get use to it and tune out. If am working on a tender though and pricing it, I do need quiet, so I tend to do that at home in my study then bring it to work and finish it into the document. We don't have any acoustic treatment,* *but I do sometimes put Classic radio on in the background helps me think and relax and adds some gentle relevance to the room."*

Maintenance 2 – *"Yes it is here as we are located on a very busy industrial estate so we get heavy lorries vibrating the building and traffic noise. We tend to work late to get some respite and work away from the office a lot, but this is not always as a direct consequence, we are sort of learning to tune it out as we are so busy. If its too noisy outside we close the windows and that seems to work."*

Maintenance 3 – *"It's a busy office here and you do get distracted with noise. We don't control the noise in any way and lots of hard surfaces, so when everyone is on the phone or we are getting a tender out it can be very distracting, and we have no where else to go. External noise is an issue with the trucks constantly going by, but we tend to tune that out. It's the internal very local noise which is a distraction."*

Maintenance 4 – *"Yes, others have probably told you. This building is a simple shed and fit out, so the acoustic properties are not great, so we get a lot of external noise coming in. As a naturally ventilated building, we also have the windows open in the summer, so again it contributes to increased noise levels. Vibration again yes, the heavy lorries passing by."*

Maintenance 5 – *"Yes it is, externally and internally, even in a central office. I get a lot of passing distractions from people talking or just moving past my door which I have open when it's stuffy. External noise I can hear which is strange, because I can't see it, so that's a bit weird. It's about the noise level and its distortion, so sometimes I get some loud bangs as someone knocks something passing my door, or I hear a long conversation at just about a discernable level, its hard to put your finger on it because you can't see it. But generally noise is a distraction."*

4.2.8 Sick Building Syndrome (Q8)

Architect 1 - *"I thought this was relevant to diseases and may be legionella so perhaps I'm not so aware what this means. I don't see the phrase being used anywhere these days so perhaps it's not a real issue anymore. In this building we seem to suffer from illnesses, when someone brings a cold into the office we all seem to get the cold. Even with NV environment we still suffer, so NV is not a total solution. If there was a system or product that could stop the transfer of illnesses that would be useful."*

Architect 2 - *"Not specifically aware of the term but I can work-out what it means from the title. From my perspective the only aspect I would say is that we as an office prefer the naturally ventilated approach to keeping us healthy, as we have a suspicion about HVAC systems and the re-circulation of air simply to offset energy* *usage. I think we would have more people off sick if we had a full HVAC system in my opinion."*

Architect 3 - *"I'm not seeing this as a prominent issue these days and I have heard of term. I don't think I have come across an SBS building and I would suggest today it's more focussed upon IAQ. With lighting improving by reducing glare and alleviating headaches for instance, and with ventilation rates being tuned to occupancy rates, problems are much fewer. Probably as a result of improving standards."*

Architect 4 - *"I haven't seen this term being used much lately, perhaps 10-15yrs ago yes, but I would say it's a building or workplace setting were its make the user feel ill and an environment were improvements need to be made as a result of temperature issues ventilation problems, smells or it could be a configuration and space issue. I think SBS is becoming an old issue. We are currently working on a 1960's building in London and it's a very poor building, masses of day-light which is good, but the façade is poor thermally as a barrier. External glare is a big issue and it is a confined busy space so blinds are required, so how to control them is our next problem. We are unable to provide openable windows so we are having to rely on HVAC systems, so again we are constraining our approach to meet specific parameters whether they are cost related or from a practical issue. We are having to work hard to improve the environment to improve the workplace for the occupant that's for sure."*

Architect 5 - *"I don't really know what it means if I'm honest, know one has never really explained a definition. The body is conditioned to adapt to harsh environments, and perhaps we have become too soft in our prescribed environments. Perhaps therefore, we need to encourage and enforce changes throughout the day in order to stimulate the body rather than have a constant consistent environment. If there is a bug in our office then the natural ventilation tends to dilute the spread of infection and we haven't see too much incidence of absenteeism, however in winter when all the windows are closed we do get a lot of colds being transferred."*

Engineer 1 - *"I would agree we don't seem to have SBS issues fundamentally, we design better these day, lighting is better and ventilation has improved, but we seem to be disconnected from the architectural folks in terms of creating better looking spaces which are interesting and stimulating. Exposed services for instance, can be quite interesting as a feature and you get that understanding of what is above the ceiling serving the workplace. If people can see things they tend to understand and accept things more readily."*

Engineer 2 – *"The issue seems to be thankfully out-dated and eliminated. ON one project the architect had specified desks with shiny reflective coatings and therefore* *the issue of reflective glare was a major contributing factor. Coupled with the lighting, the windows were sealed and the ventilation system was not adequate, so levels of CO2 where outside the appropriate limits. Both of these factors are recognised for contributing to health issues particularly headaches. We subsequently made the improvements and the classrooms and occupants were then free of the complaints."*

Engineer 3 – *"Somewhat before my time I think I'm not aware of the term. I do remember our last office in the West End causing significant issues in terms of health affects. If we had a cold in the office then everyone got it, we were so tightly packed in the space and the air conditioning was so inadequate in transitioning us between outside and inside environments. We were just in a warming box which the bugs must have loved."*

Engineer 4 – *"Yes I would agree SBS is not an issue today, but I don't know if we are designing better or we have learned to avoid specific issues which would fundamentally create SBS issues. I think we do occasionally still get it wrong, but it's more a case of trying to achieve something outside of what standards can deliver. I think it's about avoiding poor quality fresh air, providing good lighting, improving air quality generally and satisfying basic human sensory and psychological needs."*

Engineer 5 – "*To me its about avoiding all those negative impacts towards health, whether its lighting glare, thermal uniformity, air quality, smells VOC's etc., or a combination. As an occupant, am I aware of the level of them, No, not unless they have a major negative affect and by then it's too late. What we need is some way of looking at SBS systems and internal factors, and then measuring them to provide data towards threshold levels, feed that back to the occupant, now that would be interesting."*

Researcher 1 - *"I think people are attributing their discomfort to other things. My suspicion is that SBS was an easy peg to hang things on, but people are now more in tune with themselves. Buildings are preforming better – not the task I think, but we have moved on into understanding and dealing with issues better."*

Researcher 2 - *"I don't think we see this as a topic that exists today. I think we are now more aware of the workplace and ourselves and designs and products have improved. Its not something BSRIA is actively concerned with anymore or even investigating I don't think, unless there are specific issues such as IAQ"*

Researcher 3 – "*If I were to define it, I would say it's an affect of the building that makes the user unwell or prevents them from doing their job to their best ability. We use to have a very large team dedicated to analysing sick buildings, but they have now virtually disappeared, we must now be doing something better"*

Researcher 4 – *"My view is that poor IAQ and IEQ factors can affect peoples health particularly negatively. For example poorer IAQ being related to headaches, itching eyes I see regularly but this could be related to the lighting as well. I think here we don't have SBS issues, but I think that many organisations are seeing different types of SBS systems that are not manifesting as serious issues as they were before. Were they are tending to be specific issues such as ergonomics, poor IAQ, and generally the workplace arrangements I think they can be quite impacting so its important to review constantly. The work task plays a big issue, its not just the cause or impact of the workplace"*

Maintenance 1 – *"Well for me, it's about impacting the user of the space in some negative way, by making them unhealthy and/or ill, or depressing them in some way. Simply that's it I think. Specifically air quality is a big problem area, levels of pollutants, dust, poor ventilation strategies, CO2 for instance all have direct impacts on building users. Smells and VOC's also have consequences as does noise I would guess."*

Maintenance 2 – *"I tend to think SBS has come and gone, and we are talking about poor air, quality, CO2 levels, VOC, particulates and smells, fumes and general airborne contaminants with a negative health impact. We spend a lot of time working in this area, so we are fairly conversant, but what we find it is our clients that tend to default to an economical solution rather than understand the key health and productivity value."*

Maintenance 3 – *"Well in my mind it's about everything that we think is good becoming a negative in a nut shell. But the key things I would suggest is poor air quality, poor desk and chair management, we are talking about sickness right, so we need to view the individual impacts to the user. Poor IEQ I suggest is about not satisfying minimum expectations and causing some form of physical issue that causes recurring absenteeism or reduction in performance."*

Maintenance 4 – "*We have better designs and knowledge now and we use buildings differently with better fit outs and material standards. I would say we are talking about air quality VOC's, CO2 levels being too high, particulates and a generally high level of absenteeism as a result. Lighting can cause headaches as we know if got wrong, so its for me it's about getting specific factors wrong and not measuring, controlling or managing them It's also about recognising the symptoms early through feedback from users, back to what I was saying earlier."*

Maintenance 5 – *"Everything we design today to meet user expectations, we could say in reverse if it's performing badly, then it is going to affect building users. There are so many systems in buildings now that anyone of them or a combination could* *have a detrimental physical effect which is one generally manifest either as irritation, headaches or sickness."*

4.2.9 Indoor Air Quality (Q9)

Architect 1 - *"Yes I am, I think I eluded to this earlier, smells, CO_2, O_2, ventilation rates. I think it's also something to do with your receptors and not being able to pick up issues early. Odours are easy, but when it's CO_2 we have no way of recognising an issue until it becomes a health impact."*

Architect 2 - *"The quality of air in the office I think – there seems to be a lack of awareness generally as we see natural ventilation as a good point, but we don't see any issues as it's the same air we breath at home within reason. Filtration and particulates are probably an issue but we don't see any issues specific to this office, unless it's borne from odours or some tangible other factor."*

Architect 3 - *"Its about achieving adequate levels of fresh clean odourless air which allows you to feel satisfied with your environment, perhaps even subjectively, and to have air which has not been filtered or treated. This is obviously dependant upon the external environment, but I think if most people had a choice they would ask for clean fresh natural air against a/c re-circulated air."*

Architect 4 - *"I think it's about achieving the right balance of ventilation air change rate inclusive of temperature. Using openable windows give us a relationship with the external air that we would normally rely upon via a HVAC system, but that is what we are traditionally used to. We generally feel better in this office because of the natural ventilation approach, and it feels more natural if you consider we don't even think about air quality even when we are outside the workplace unless we have excessive fumes."*

Architect 5 - *"You come into a room and it feels stuffy so you open a window, that's generally how I view IAQ. I think we need to consider IAQ, but should a building actually be moderating you from everything around us, or should it be keeping you connected to the outside space?. Perhaps in London and hi density areas we do need protection from poor air quality, but it carries a cost we need to be aware of as designers. IAQ is important for sure, but we need to understand the external and internal environment separately before we accept any holistic solution."*

Engineer 1 – "*Keeping dust down and to ensure you have good levels of humidity in the air. Other than that I don't think there is much else to achieve. Particulate matter is an issue for me because I do sneeze a lot when in the office and yet nowhere else. It would be interesting to undertake a particulate study. If I am late in the office at* *about 19:00 the ventilation goes through a building purge so the ventilation system ramps up and then I start to sneeze. I'm like an intelligent dust sensor."*

Engineer 2 – *"Stuffiness is how I would basically describe poor air quality so avoiding this would be a step in the right direction for creating good air quality. CO2 management is also key, as well the right ventilation rates. The dilemma I see however, is that we do not measure air quality within the workplace we don't even monitor CO2 levels and I see little adoption or specification requirements previously, now or in the future. I think we should look to monitor and measure air quality and integrate the data into the buildings control philosophy."*

Engineer 3 – *"If I try to describe the term poor quality I would say it's about lack of fresh air, warm, stale, smelly air and it being to humid, so if you transpose to the opposite, that would be good air quality. CO2 levels would also be an area of concern, as you can feel tired if the CO2 levels increase too high. I'm not sure what the levels are but I know its has a negative effect if the levels are too high and you start to feel lethargic and tired."*

Engineer 4 – *"Indoor air quality after all, is about taking external polluted, contaminated dirty air and removing these aspects using filtration or air treatment, but we must start to think about monitoring, measuring and managing it. Monitoring CO2 levels as I have mentioned is a key aspect we need to incorporate more, this is fundamental to good air quality, it's a fundamental constituent element we cannot ignore. We simply don't do enough monitoring, and it's fundamental to occupant health and well-being."*

Engineer 5 – *"What surprises me, is that we don't measure internal air quality as we do with the external air pollution, nor do we compare it to see how well the building systems are performing in managing and controlling the air as it enters the space we occupy. So I suppose we are looking at the ventilation strategy, managing air quality and its constituent elements, and for us to deliver fresh air based upon feedback from within the space. We have so much technology for offering high quality air, but how far do we go in terms eradicating smells, particulates, viruses, bugs and general pollution. It's an interesting thought pattern to suggest we should measure more, it seems logical, but what do you do if you have a NV building. Measure anyway I suppose and feedback."*

Researcher 1 – *"Its common that people do not understand what air quality is, but at the extremes I think people can assess and reflect upon the differences particularly externally. In buildings we don't seem to have a metric which associates* CO_2 *to performance where as we can in school and animal houses were growth and development for instance can be measured"*

Researcher 2 – *"I would suggest that IAQ is not measured, it's not controlled sufficiently and its not considered a vital performance factor. I think we need to look at ppm CO_2, odours, CO levels, particulate control, (dust etc), ventilation rates, VOC's to an extent (but not so much these days) and provide a deliverable, quantifiable metric for IAQ which is available to the building occupant. We are now addressing IAQ as part of an IEQ approach here at BSRIA, but it's early in the process as it's such a mind change"*

Researcher 3 – *"We have a team here at BSRIA who specialise in IAQ, so in my opinion it's about CO_2 level dust and particulates and making the space fresh and odourless. The fumes we can smell in the summer are quite high due to the traffic outside so that's an issue, but we don't conduct any analysis. It will be interesting to se what the CO_2 levels are in the winter"*

Researcher 4 – "*We don't seem to manage CO_2 properly neither do we monitor or control it adequately. When we look at the definition and the constituent elements of IAQ, we only touch on a small area. For instance we don't generally measure particulates, CO_2, VOC's, Virus or dust etc, we seem to let the occupant become the sensor and by then it's too late for prevention"*

Maintenance 1 – *"One thing we should do is measure and monitor indoor air quality better, we just don't do it. Flow rates and filter differentials yes but that doesn't tell us anything about the quality of the air we are breathing inside. Yes….. it would be good to compare the outside air with the inside air, and then to see how well the buildings systems were performing. We could then put them against health standards and make a case for investment or not who knows yet."*

Maintenance 2 – "*I would suggest that we should treat air as a valuable source of energy as we do with clean drinking water, any contaminants within water can have a severe health impact and we monitor and control water quality stringently, we don't do that with workplace air, its simply filtered, warmed or cooled and displaced into the workplace."*

Maintenance 3 – *"It is certainly different from external to internal air and even re-circulated air used in many HVAC systems today. CO2 is a major issue which has a direct effect upon building users and to an extent so do pollutants, but they are at much higher levels than CO2 so in the main its about managing CO2 levels, humidity, dust and particulates and preventing or eliminating bacteria and virus transmission."*

Maintenance 4 – *"Measuring, monitoring and interpreting air quality values will be a major step forward for the industry, but it needs to be applied pragmatically for each building. It also needs to be relative to outside air, and thresholds reported in some* *way. So…good air quality is about managing CO2, filtering particulates smells and odours, thermally acceptable, the right flow rate, pollutant free if possible, and free from bacteria and viruses."*

Maintenance 5 – "*To understand the constituent parts, of CO2 as a main example and particulates will in the main solve many issues from lethargy, to the transfer of airborne contaminants and illnesses. Good air quality is so important, but we don't measure it or monitor it. Providing fresh air when it comes in from the street, we need to clean it, remove all the possible contaminants and then temper it and push it into the space so that know one notices it. It's also about killing any bacteria or viruses that are carried on any particulates."*

4.2.10 Workplace IEQ Factors (Q10)

Architect 1 - *"It's a mixture of different things for me, ergonomics, noise, lighting, bigger monitors for my work are my big 3. Drafts are a problem, so I think good ventilation is important and some finer control would be useful. Breakout space is essential to get away from your machine and desk, but we need to be together for teamwork."*

Architect 2 – *"Never suffer from any factors, no negative issues affecting me personally. I think the space is designed well, I can definitely see the difference from the old office to the new office and everyone seems quite satisfied generally. The only negative issue I really have, is the design of the full height fresh air vents, I would like to have full occupier control rather rely upon the central BMS and in-house engineers."*

Architect 3 – *"I think it's about choice and it's about control for the occupant and offering the option to interface in a practical way with the building systems rather than having the building doing everything. We should be part of the building but not as dumb sensory extension. Cultural colours and graphics are important, but there is a place for restraint on this aspect. We should be focussed upon work rather than consciously being affected by the workplace, it is there to support us in achieving the task not to become a distraction within itself."*

Architect 4 – *"If you are invigorated by the workplace, the culture and the look and feel of the office, then you tend to accept your environment and adapt to it. You see the work task as the key aspect of satisfying your basic needs and the workplace is becoming more a secondary but still important stimulant. We measure productivity in numerous ways, but we don't have a right or wrong answer to this. As architects it's about creativity which is difficult to measure. Perhaps it's about quality and how we use the space, or it's about getting the job out the door."*

Architect 5 – *"Good IT matching the brand value of the business and the occupant is essential, the world is moving so fast the work task has become the focal issue. IT and the workplace should be flexible, adaptable it should be economic and sustainable. I didn't mention building services did I, that in my opinion comes from good sustainable design, the building services should be a given deliverable."*

Engineer 1 – *"It should provide good space, chill out space, work orientated space so we can get the job done, clean and bright with an airy feel to the space is important for me. It's important that it doesn't impact what I am trying to do, but I need my senses to be satisfied and stimulated in a positive way. Fresh air so I don't feel tired and thermal comfort is vital, but I think some adaption is required to satisfy everyone within the space. I don't generally think about the space unless it's causing me an issue, I adapt generally."*

Engineer 2 – *"I thinks it's primarily about thermal comfort and delivering acceptable environments which we do not have to think about or manage. Noise control, indeed management, should be a real consideration within the design process, and not just a sterile acoustic issue as we as services engineers tend to adopt. Air quality should have a higher visible presence in the design process, and end-user feedback should become a fundamental deliverable."*

Engineer 3 – *"For me it's about the space being cool, clean and offering us break-out spaces. The job task is what we are about, we tend not to think too much about the space we just seem to adapt, but the task is what we have to achieve."*

Engineer 4 – *"For me as I have touched on in other questions, it's about the environment being clean, tidy, thermally acceptable, clean toilet facilities, appropriately illuminated, having the tools to do the job and having a desk and chair ergonomic solution would be good. The softer elements I think are important, the breakout space, tea & coffee, storage, colour, vistas stimulus generally are all important. The HVAC services yes are essential, but they are secondary providing they are working properly."*

Engineer 5 – *"Having pleasant breakout spaces and good views is very important, bringing a home view into the office is probably another good step, and maybe educating occupants as to their environment. Data and knowledge seems to pacify people even in negative situations, so feedback is very important. Sadly very rarely does it exist in any of the buildings I know of."*

Researcher 1 – *"Density is not a problem here despite what its look like, and we continue to advise people to design to lower densities which I think provides occupants with better space relationships. If we put more in the space then we need to have better control of the individual space, visual environment, lighting controls* *and a well arranged space being interesting rather than repetitive in order to improve the experience"*

Researcher 2 – *"Air quality is a big one for me, vistas as I said, I think you have to feel secure at your workplace not so much security more comfortable in your space as you feel at home. But its temperature, connection with the outside, and a space that just preforms at the basic level and which satisfies the basic occupant needs and values that I'd say"*

Researcher 3 – *"BSRIA has a plan to move forward with change, but it's all business focused and not workplace focussed, everyone seems content but that doesn't mean they are working at their best. I suppose air-conditioning would be a choice for summer because it does get very hot in the summer, but everyone adapts in some way either by using a fan, opening the window or dressing accordingly."*

Researcher 4 – *"a perfect workplace to me is one that has perfect IEQ factors, it doesn't have to exceed expected norms, it just needs to meet the norms and adjust where possible to personal individual requirements. I think having the right desk, position, location and facilities is more important than achieving perfect IEQ conditions, the more human approach. Obviously having a good workplace is important, but providing the best ICT will in my opinion always provide greater personal satisfaction by getting the job done with less stress"*

Maintenance 1 – *"Simply, don't' make me ill, give me everything I need to do the job. Not saying it's about the buildings systems they should just work, it's about the whole experience of how the organisation operates and runs the space, and importantly, what it looks like. Life is fast enough now, so the workplace where we spend 70% of our time needs to understand us as human beings."*

Maintenance 2 – *"Well-being and performance two issues. Well-being I think we should focus on the building environmental factors the things we service and look after for our clients. Performance is task related and therefore I see this being about the specific workplace factors – desk; chairs tools and ICT, however, still reliant upon the environmental factors."*

Maintenance 3 – *"I think the occupant expects to have a secure, pleasant and safe workplace were they can work to earn, and to what ever satisfies them. Well-being, I would suggest they look for the space to be clean, quiet so they can work given they are now in a space occupied by many, and to be provided with could air quality and thermal comfort. Performance and satisfaction two different things I would say, and the workplace tools and factors certainly drive performance."*

Maintenance 4 – *"Well it should meet my expectation rightly or wrongly, interface with me to provide some sort of connectivity, and it should be invisible to my needs.*

Well-being is about cleanliness, so air quality is right up there, but sadly being ignored by so many, so its then about the space itself I suppose, and how well its been designed by the architect. Is everything easy to use, get at and operate, that's my view?."

Maintenance 5 – *"Slightly in reverse order…for our clients we are certainly delivering to their expectations, the problem is they don't really understand these expectations nor do they see the longer term benefits of investment. Well-being; its about good air quality, adequate and controlled lighting, thermally acceptable spaces winter and summer, and a well designed and laid out workspace, so that you have everything you need to do the job. Performance and satisfaction all the above, but some softer issues within the space would be nice; break out areas, communication areas and a pleasing visual and relaxing environment."*

4.3 Semi-Structured Interview Summary

Within this section a series of views were collected in terms of what is seen as important across a spectrum of subject matter experts and as building occupants. Table 39 indicates the key issues noted from the interviews. The feedback from the SME's was used to construct the POE survey detailed and elements of the AHP importance questionnaire.

Some of the more interesting feedback during the interviews was the general acceptance that the workplace was secondary to completing the task and that integrated feedback would be useful. The changing nature of work and the places work is conducted is fundamentally changing, through hot-desking, causal spaces and the tasks being performed becoming more ICT supported. Workplaces should just be spaces with minimal conscious impact to allow the task to be performed.

The key aspect associated with this research confirms occupant and building bi-directional connectivity were feedback would be extremely useful. However, there is some real concern at the ability of current BMS to successfully mange this task given the complexity of the integration across many demands and systems.

At the system, protocol and inter-connectivity level of building devices, this will need to be fundamentally addressed to allow such functionality to exist. None of the respondents could advise as to what level of integration should be achieved, however, this was assessed as the lack of available knowledge in this area. In addition the ability of systems to affectively control multiple occupied spaces all with specific individual requirements is seen as a major obstacle.

Semi-Structured Interview Keys Responses		
Q	Question *(short form)*	Key Responses/Comments *(words)*
Q1	Clean Fresh Air	Control of smells; Seasonal awareness/management; external internal differences; definition of cleanliness & freshness; relative to location; expensive; available technology; lack of clarity within standards and regulations; how to measure and present; lack of investment to achieve best practice.
Q2	Inclusive Day-lighting and Artificial Lighting	Light spectrum; colour rendering issues; external control by façade; interval control by system; internal; external light levels controllability; external glare; manual/automatic control; measurement essential; energy saving controls; internally bland lighting schemes; daylight perimeter controls; uniformity issues connecting daylight with internal lighting; dimming options; external blind control; investment effectiveness.
Q3	Integrating Thermal Comfort	Cost prohibitive; level of intervention; occupant interface; system awareness; understanding the issues; intelligent learning systems; Complexity; inter-operability problems; manual + auto intervention; home v office why the difference; variation; individual requirements; transitionary spaces; where and how to measure; feedback essential; artificial intelligence;
Q4	Intelligent Building Controls	Feedback strategy; what protocols; poor functionality with current BMS; philosophy; vision; interface; not to complicate; occupant requirements; minimal control; maximum feedback; user interfaces; portals; apps; phones; what to control and feedback; sensory exchange information; no psychological response; Helpdesk automation; common simple language.
Q5	Workplace Standards and Inter-Operability	Engineering/architectural standards; common language; alignment; demographics; IEQ framework of ideas; energy savings; lack of guidance; consistency; life cycle benefits; multiple platforms; feedback; individuals.
Q6	Occupant Satisfaction and Well-being	Ergonomics; reducing absenteeism; break out spaces; quiet spaces; IAQ; acoustic control; IEQ factors essential; CO_2 monitoring; measurement; feedback; invisible factor; day-light; dimming; No hassle; Good quality ICT; simple operations; germ control; pollutants; management.
Q7	Noise & Vibration	Hearing; poor acoustic design; quiet zones; internal external noise intrusion; definition of noise; architectural design; hard surfaces; distraction; concentration; reverberation; meeting room noise transfer; background noise; intrusion; seasonal differences;
Q8	Sick Building Syndrome	Historical; improving standards; ventilation; CO_2 control; measurement; lighting; IAQ; thermal management; sensory needs; levels; thresholds; feedback; smells; VOC's; economical default; particulates; knowledge; symptom recognition; how to measure; control; feedback.
Q9	Indoor Air Quality	Human receptors; sensors; recognising; lack of awareness; connectivity; internal; external; holistic; solution; contamination; pollutants; measurements; feedback; fundamental; constituent; control; bacteria; viruses; bugs; particulates; quantifiable; metric; definition; energy; analysis; standards; investment; illnesses; air quality v water quality;
Q10	Workplace IEQ Factors	Ergonomics; break out space; IEQ factors; cultural; colours; choice; sensory; work/task focus; building secondary to task; good ICT; simulated; sterile; acoustic design; vistas; softer elements; solutions; pleasant; feedback important; visual; controls; basic needs; individual requirements; best ICT: security; safe; cleanliness; adequate; acceptable; relaxing.

Table 38 - Key Semi-Structured Interview/Survey SME Comments

A keep it simple principle therefore appears essential to maintaining good quality buildings. If we over complicate the building controls, likelihood is when the systems fail, IEQ factors will become a major issue.

One specific element not expected was the measurement, control and management of illness from bacteria, virus and "bugs" something very little attention is offered currently. More attention seems to be needed in this area and sufficient technology exists to contribute a solution, however, it is likely to be cost prohibitive unless tangible benefits can be realised.

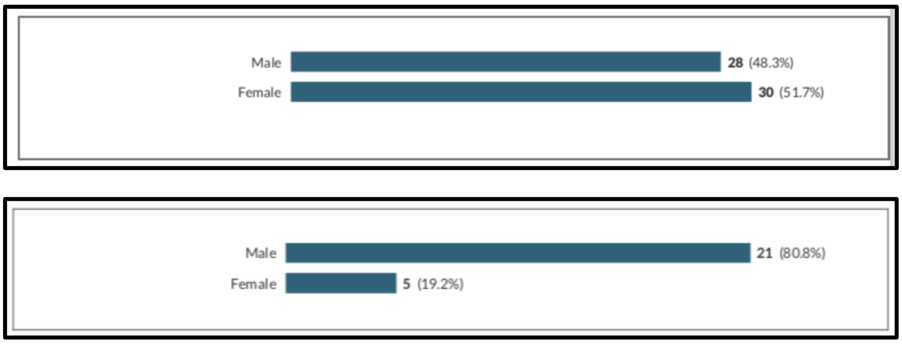
Therefore in summary, the key aspects determined which contribute to achieving a better workplace can be assessed as follows:

1. Improving fresh air knowledge, awareness and affordability.
2. Development of integrated and robust feedback and control systems.
3. Improvement in standards, interoperability and guidance documents.
4. Defining IEQ factors and driving better knowledge exchange and awareness.
5. Overall agreement for connecting the building and occupant together.
6. Noise remains a significant issue to solve by better architectural design.
7. Thermal comfort although understood is still a key issue to manage.
8. Indoor air quality needs to be defined and made more affordable.
9. A need to address airborne contaminants previously ignored.
10. IEQ factors need to be mutually connected to create a better workplace.

4.4 Post Occupancy Evaluation (POE) Survey Analysis

The POE surveys were conducted at 5 Plus Architects and at BSRIA during 2016 as detailed within Table 38. The purpose was to assess if the standard IEQ factors within both locations represent existing common understanding. The subsequent intent being to assess the feedback obtained from the semi-structured interviews and appliy both in a review of the AHP survey and results.

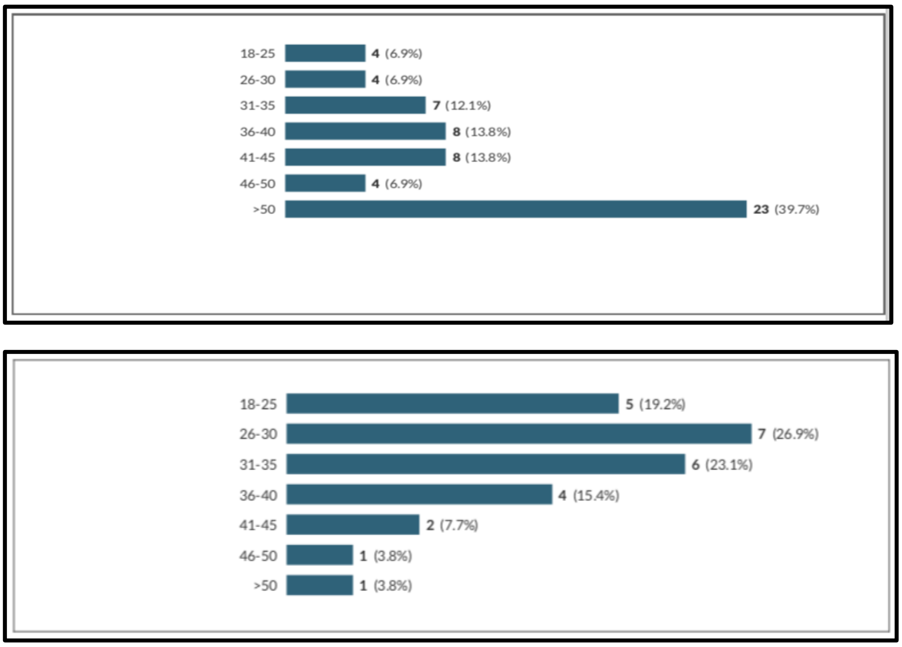
The following graphical comparative analyse is provided within Fig's. 38 to 61 Questions 1-9 within the survey represent the individual site demographics, with questions 10-25 focusing on specific IEQ factors.



BSRIA

5Plus

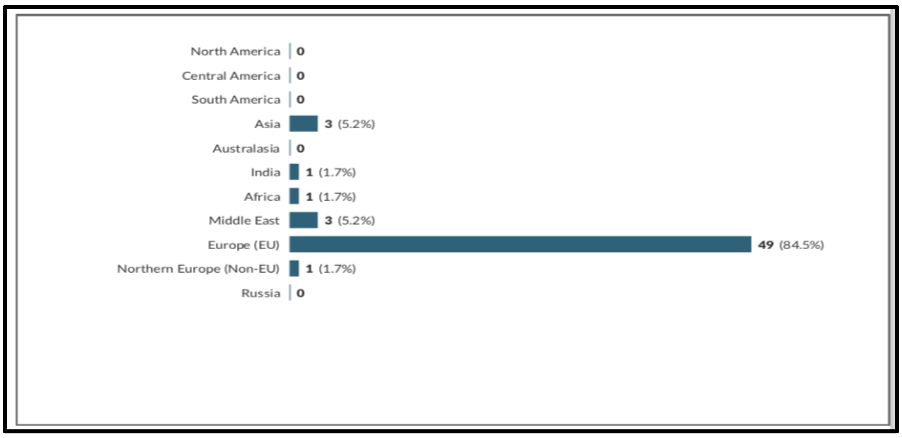
Fig. 37 - Q2 - What is your gender?



BSRIA

5Plus

Fig.38 - Q3 - What is your Age group?



BSRIA

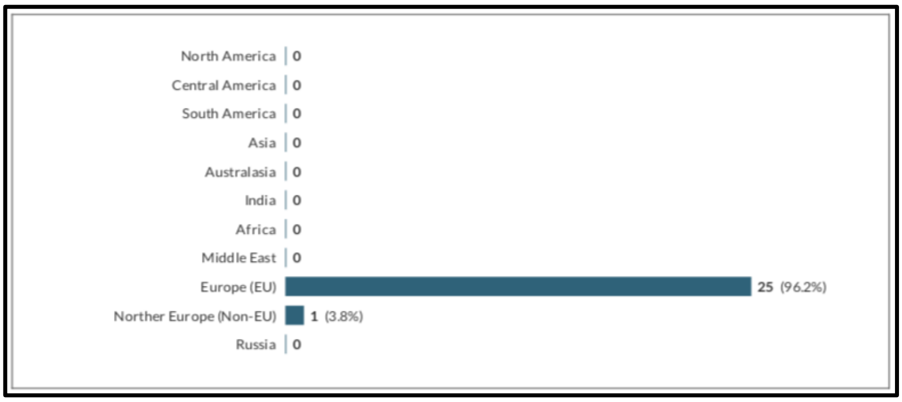


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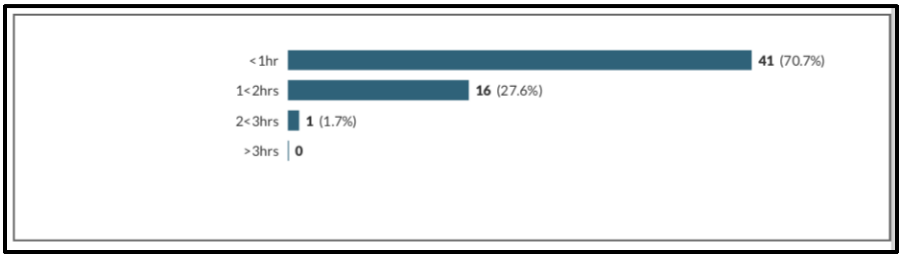
Fig. 39 - Q4 - Region of origin



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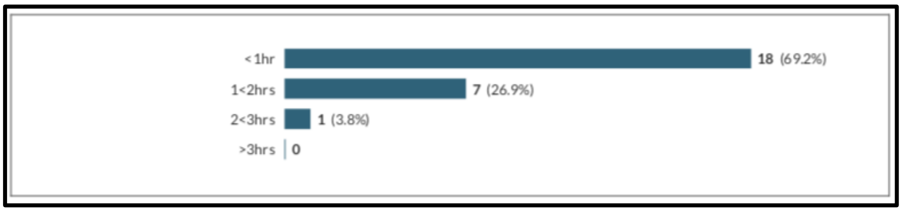
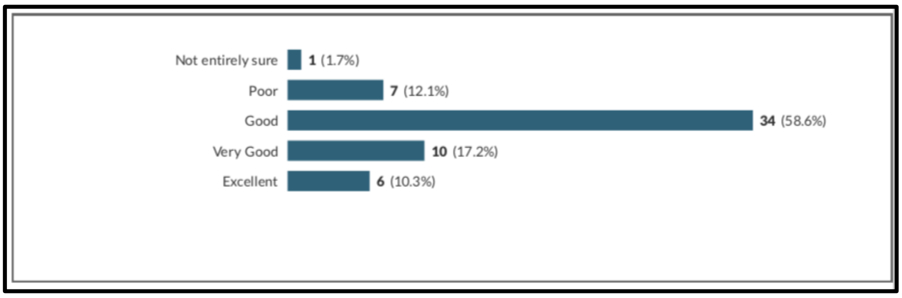
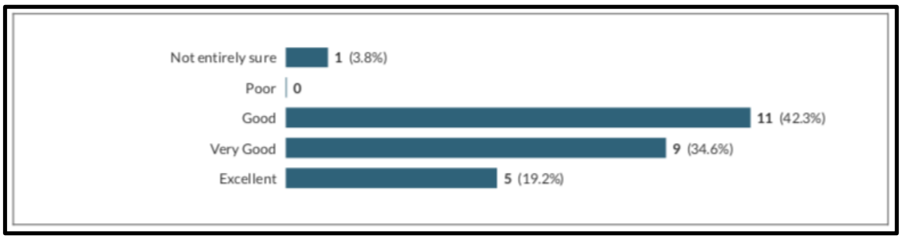


5Plus

Fig. 40 - Q5 - Travel time to and from work per day.

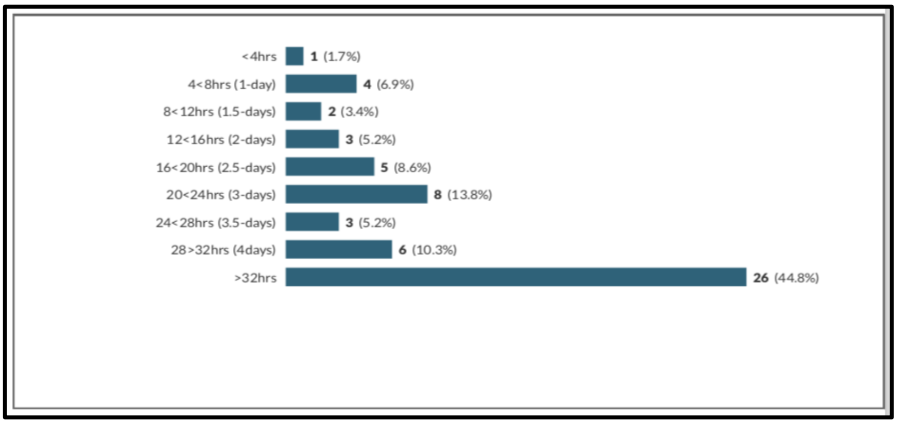


BSRIA

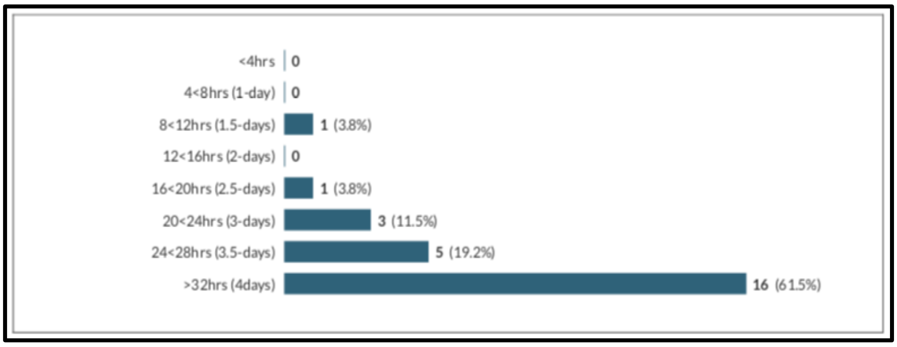


5Plus

Fig. 41 - Q6 - How would you classify your overall feeling of health and well-being when in the office?

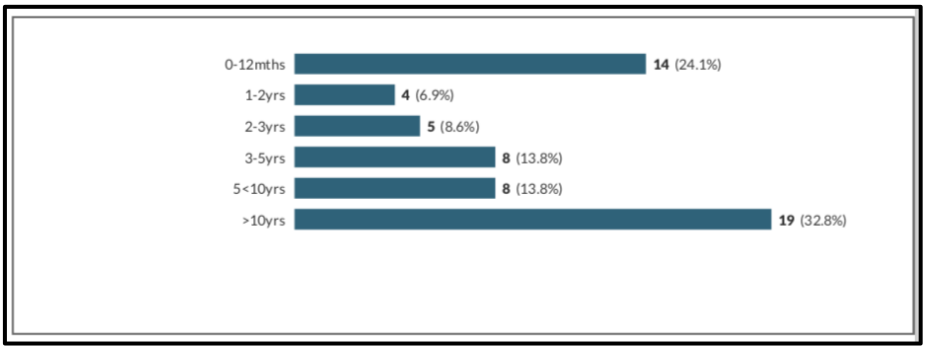


BSRIA

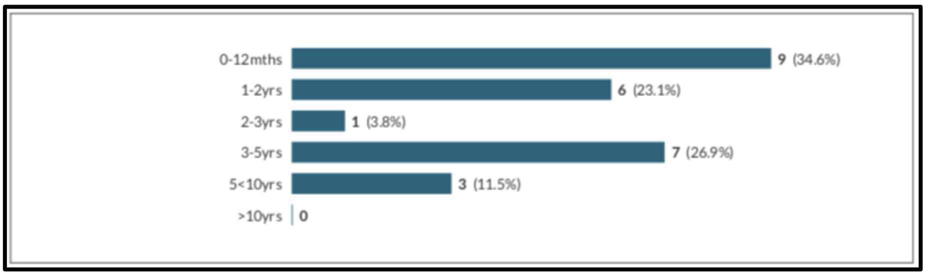


5Plus

Fig. 42 - Q7 - How many hours would you say are spent at your desk during a typical week?

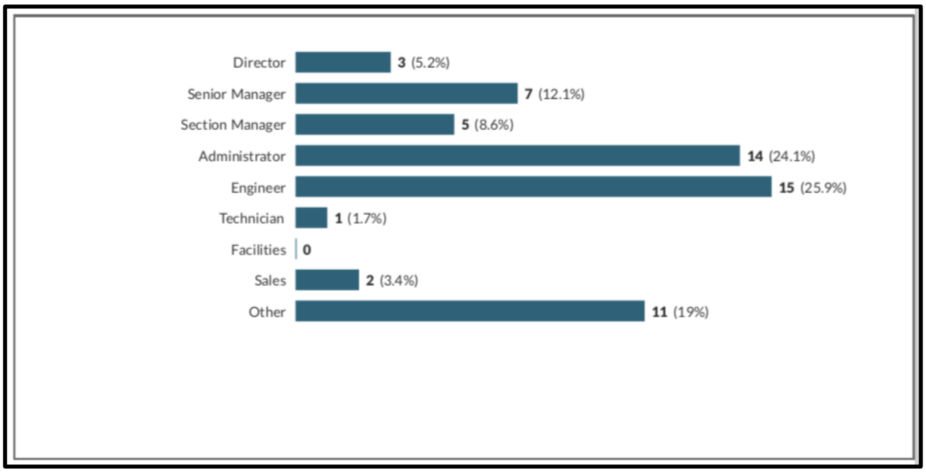


BSRIA

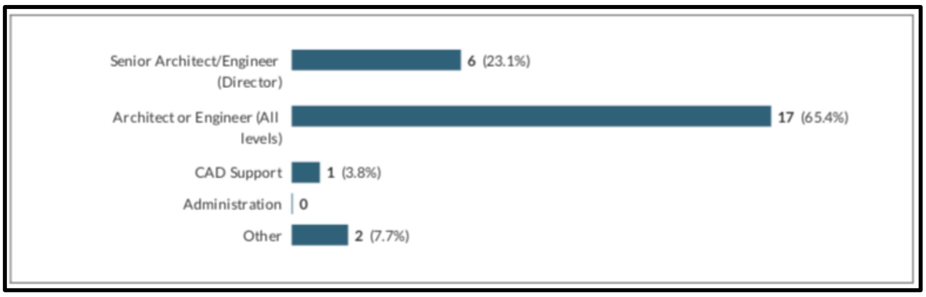


5Plus

Fig. 43 - Q8 - How long have you worked for your current organization

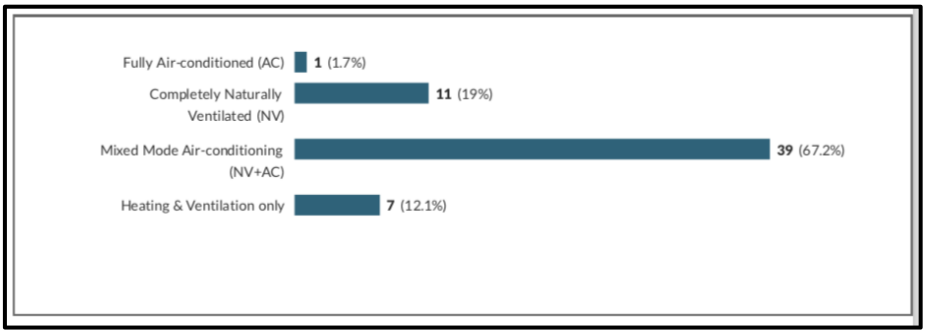


BSRIA

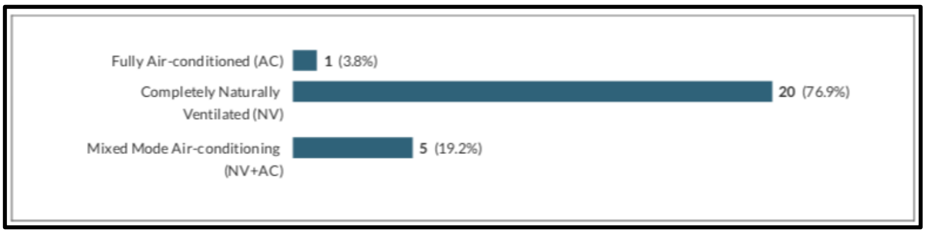


5Plus

Fig. 44 - Q9 - Which of the following best describes your role within the organisation.

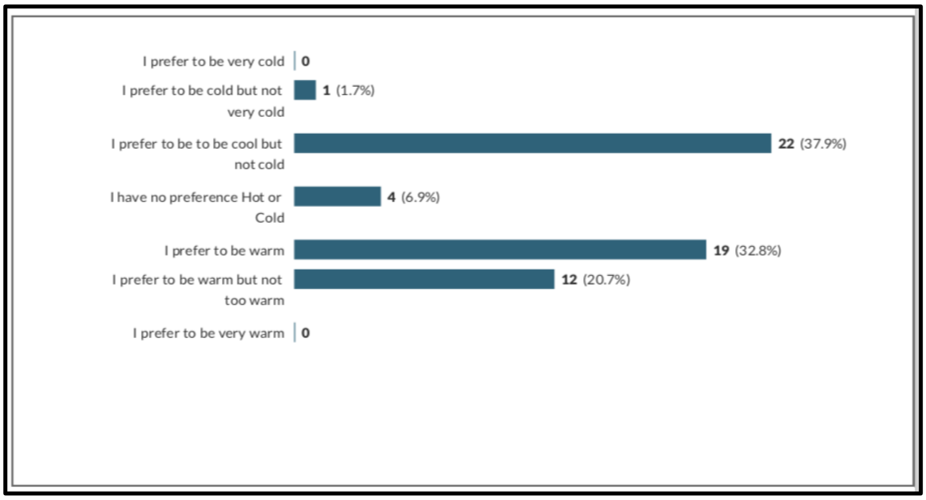


BSRIA

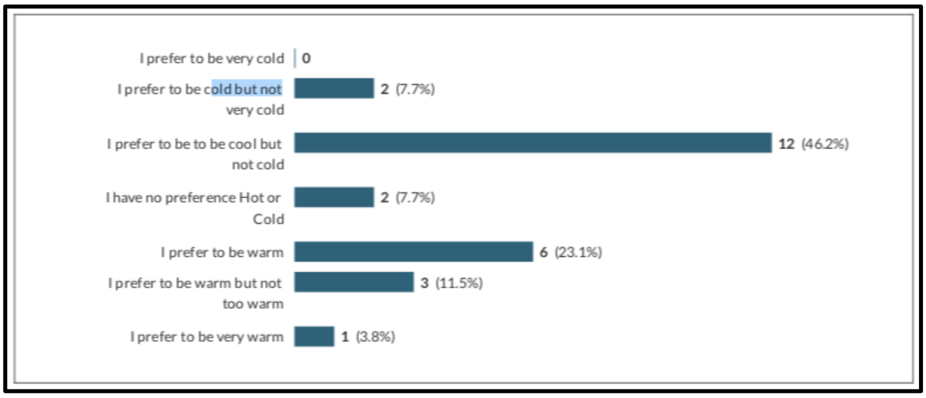


5Plus

Fig. 45 - Q10 - In terms of providing a comfortable workplace, which of the following environmental systems would you prefer to work within?

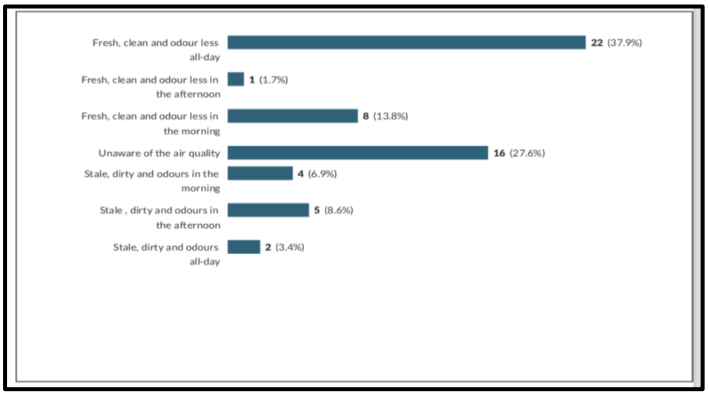


BSRIA

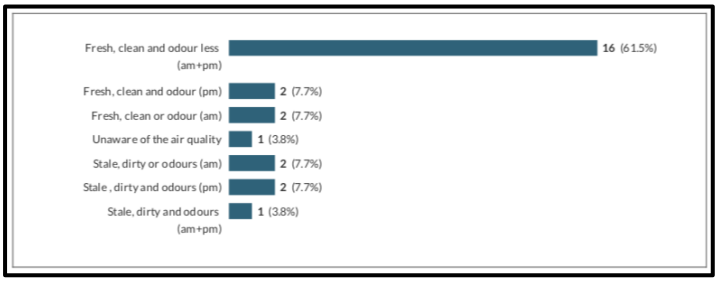


5Plus

Fig. 46 - Q11 - If you were to describe your general preferred state of thermal comfort, which of the following best describes where you feel most productive?

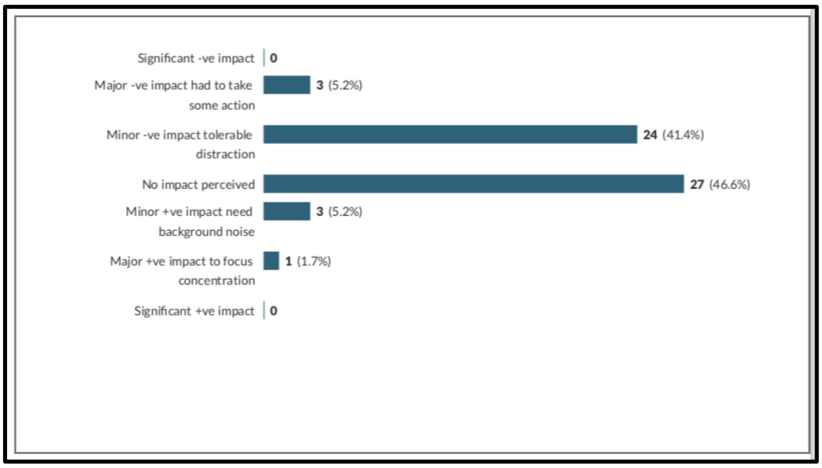


BSRIA

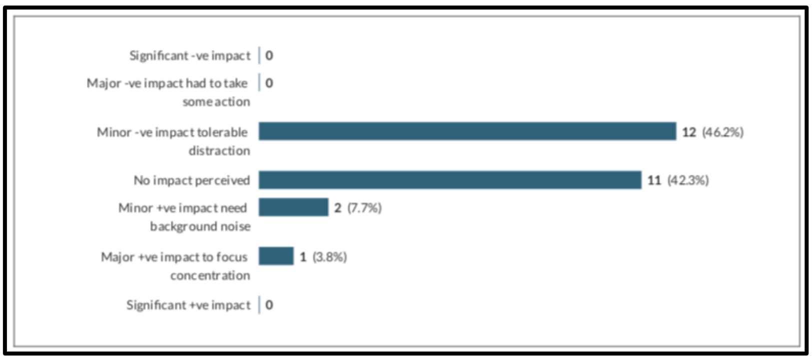


5Plus

Fig. 47 - Q12 - Overall how would you describe the Indoor Air Quality (IAQ) within your workplace environment?

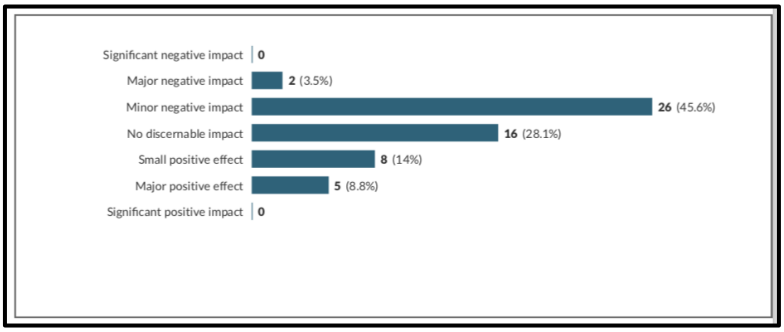


BSRIA

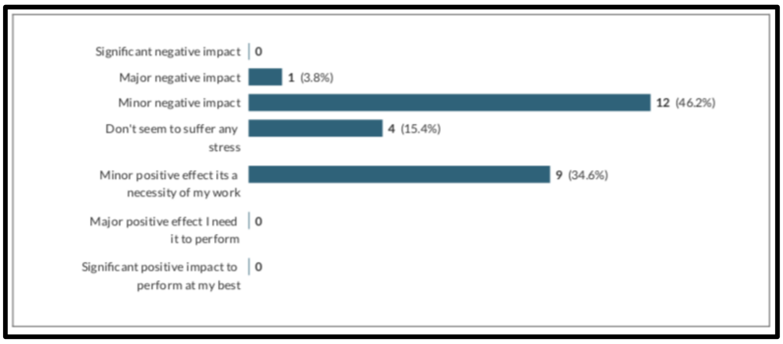


5Plus

Fig. 48 - Q13 - Recently has any type of noise within your environment or externally affected your productivity or performance?

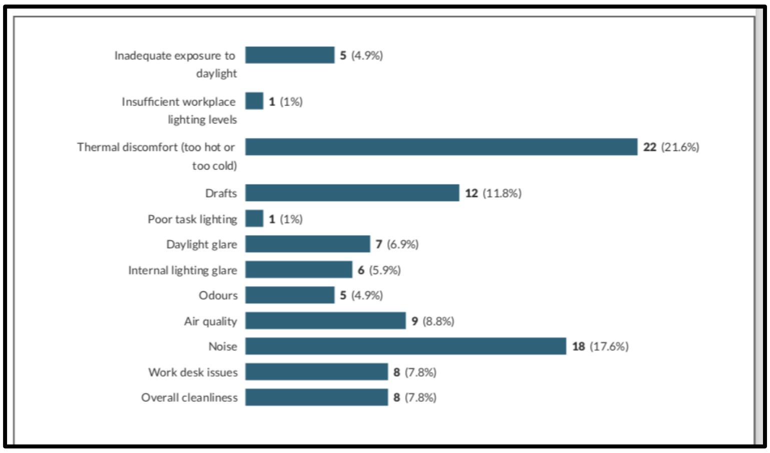


BSRIA

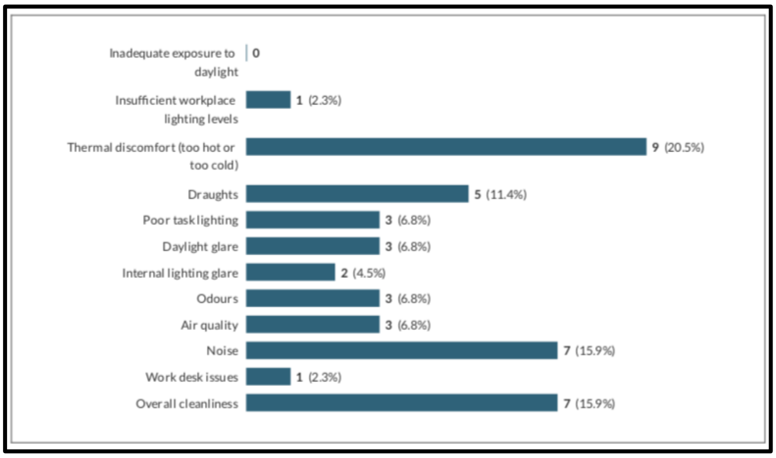


5Plus

Fig. 49 - Q14 - When working in your office, would you say the workplace environment has any of the following impacts?



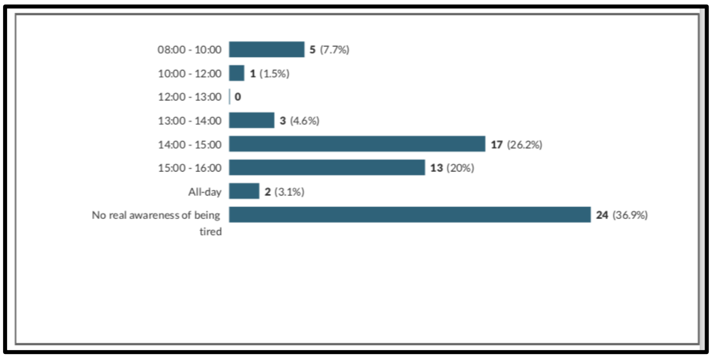
BSRIA



5Plus

Fig. 50 - Q15 - Over the past 2-weeks, have any of the following building orientated aspects affected your work performance?

BSRIA



5Plus

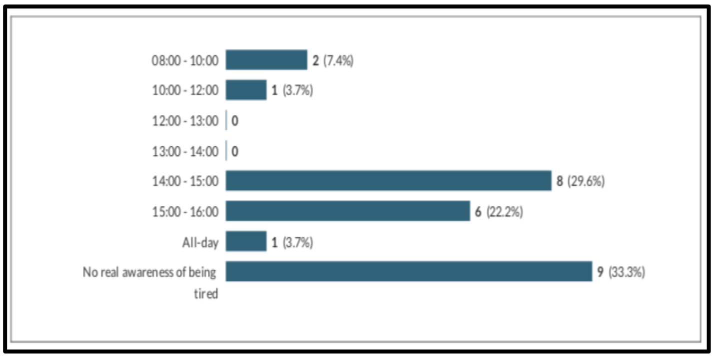
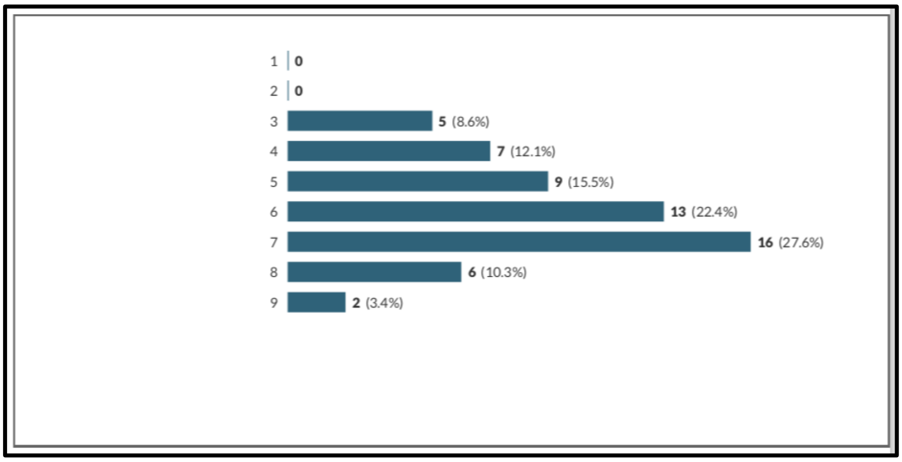
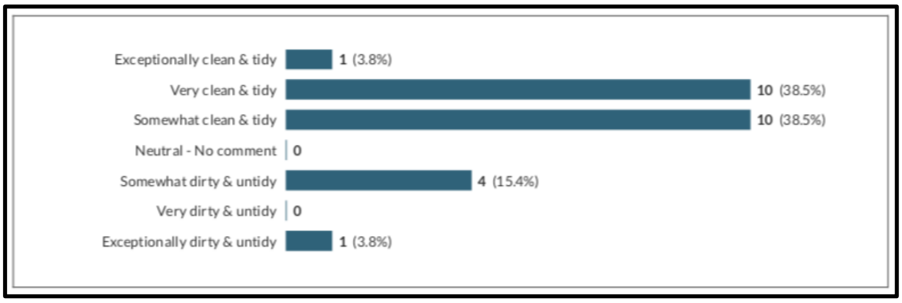


Fig. 51 - Q16 - Did you feel specifically tired or fatigued during any of the following times over the last 2-weeks?



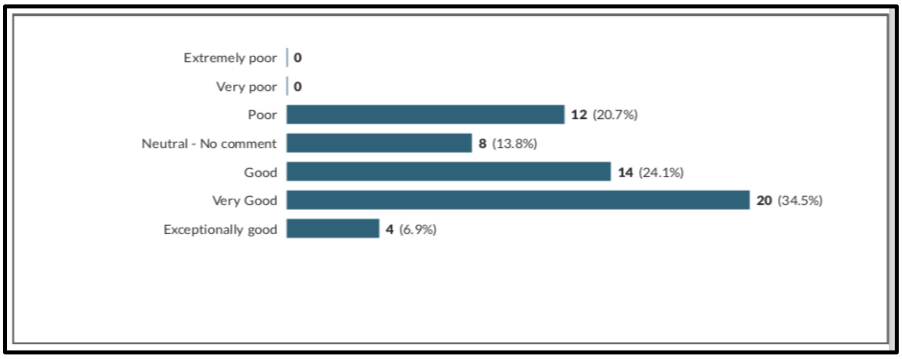
BSRIA



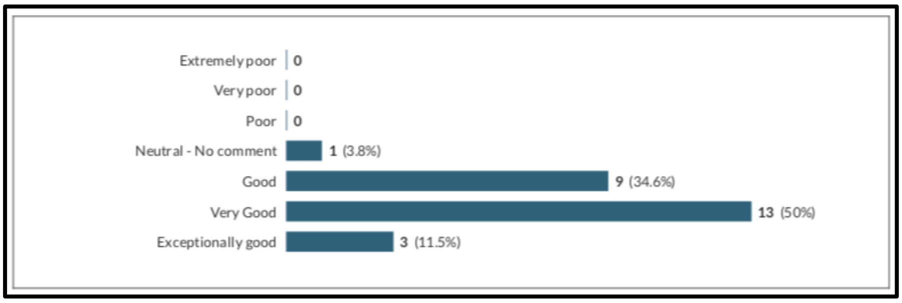
5Plus

Note: BSRIA requested a different format for scoring cleanliness.

Fig. 52 - Q17 - On a scale of 1-9 how would you rate the general level of cleanliness within your office? (1 being poor - 9 being excellent).

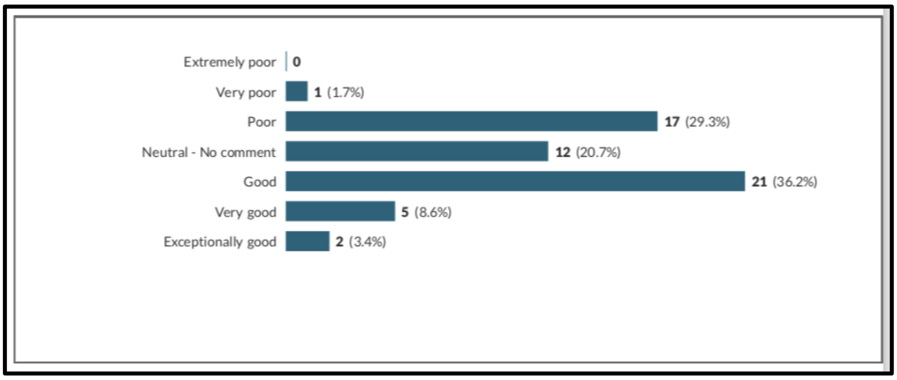


BSRIA

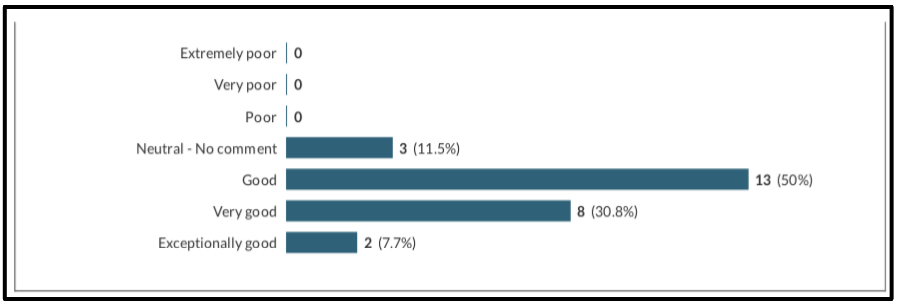


5Plus

Fig. 53 - Q18 - What is your overall opinion of the daylight available within your work area?

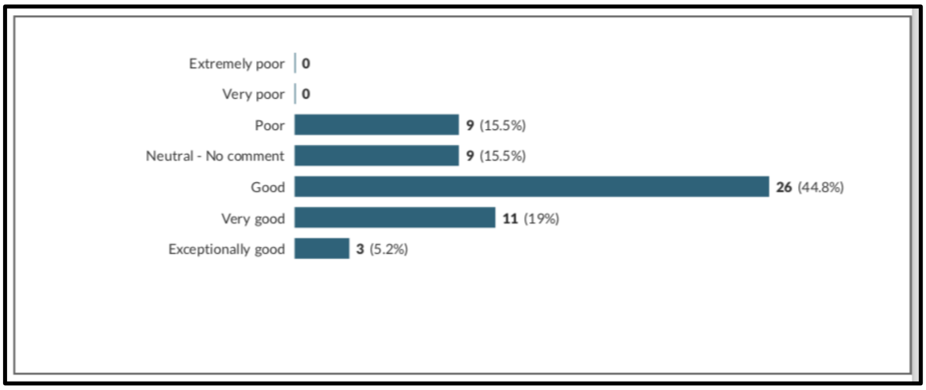


BSRIA

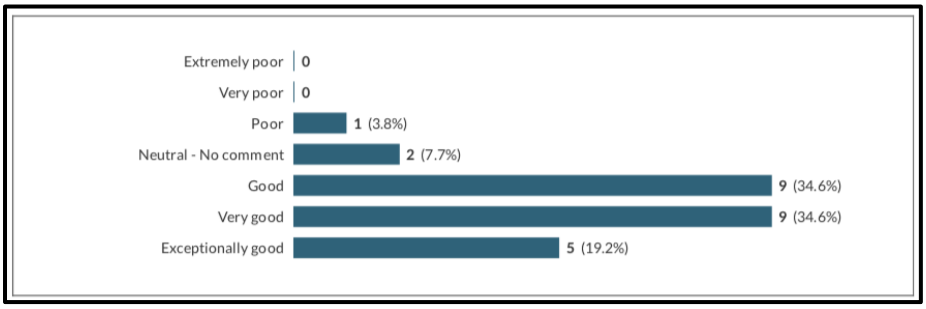


5Plus

Fig. 54 - Q19 - Similarly what is your opinion of the artificial lighting?

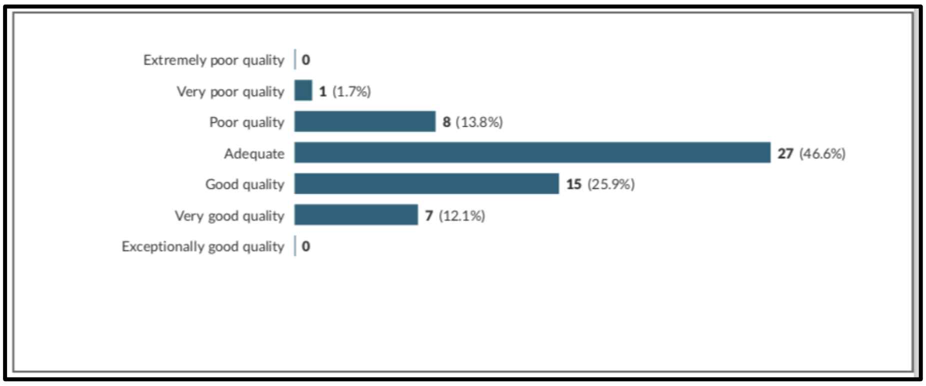


BSRIA

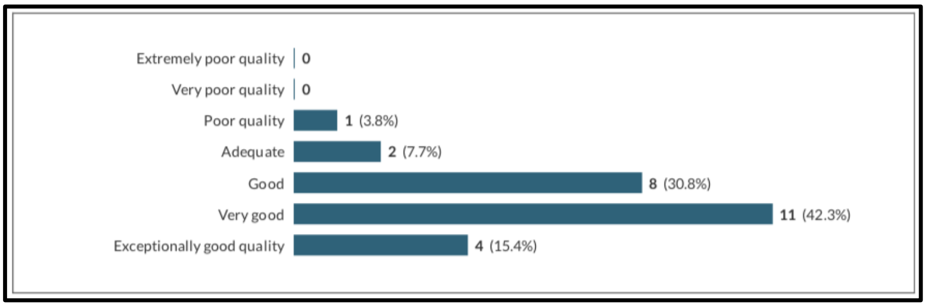


5Plus

Fig. 55 - Q20 - How would you rate your overall work space arrangements, tools and equipment to enable you to be productive and satisfied?

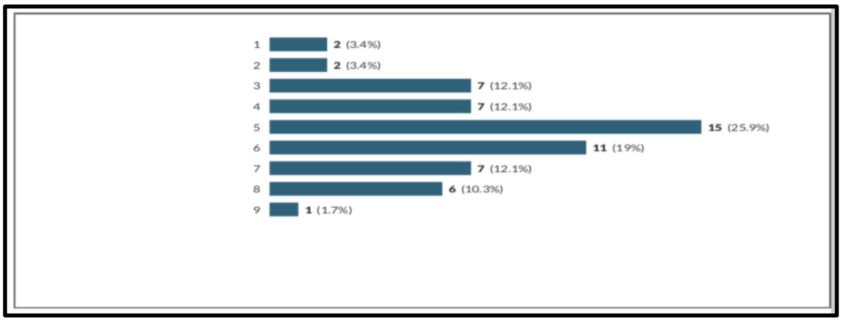


BSRIA



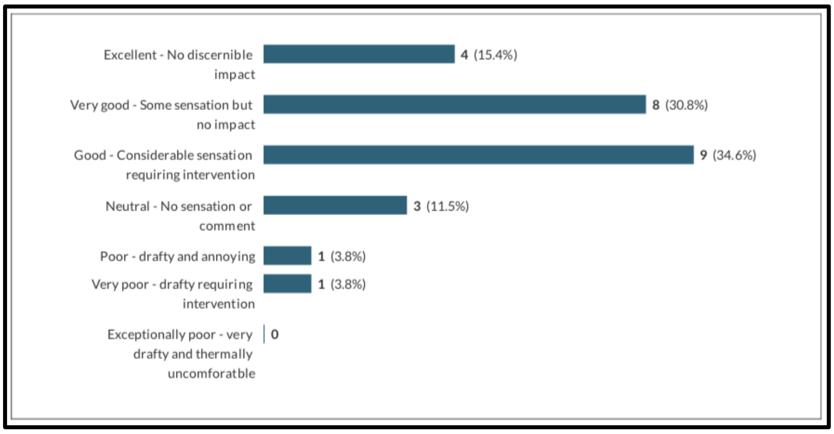
5Plus

Fig. 56 - Q21 - Perceived indoor air quality is a very subjective topic across many building occupants, what is your own perception of the air quality within your own workplace?



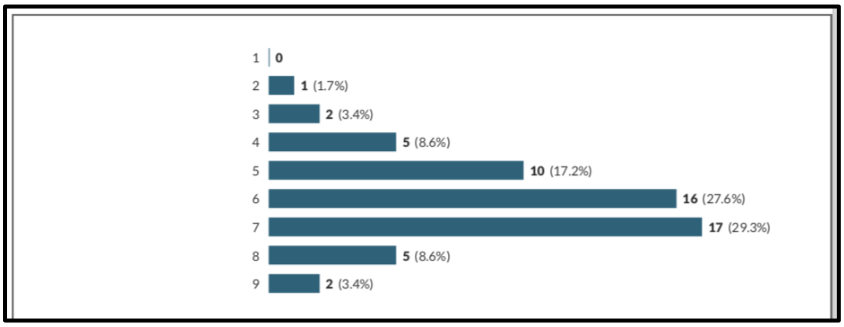
BSRIA

Note: BSRIA requested a different format for scoring air movement.



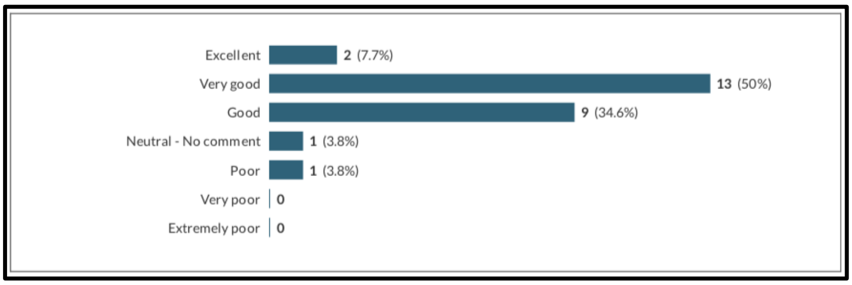
5Plus

Fig. 57 - Q22 - On a scale of 1-9 how would you rate the ventilation or air movement within your office?



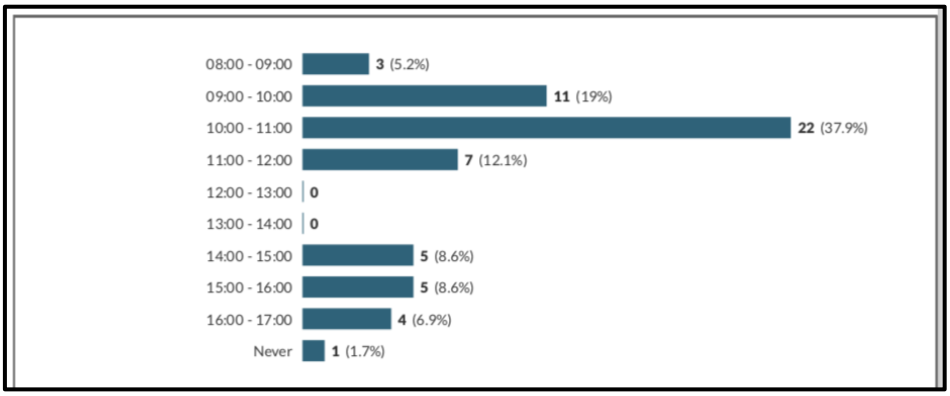
BSRIA

Note: BSRIA requested a different format for scoring well-being.

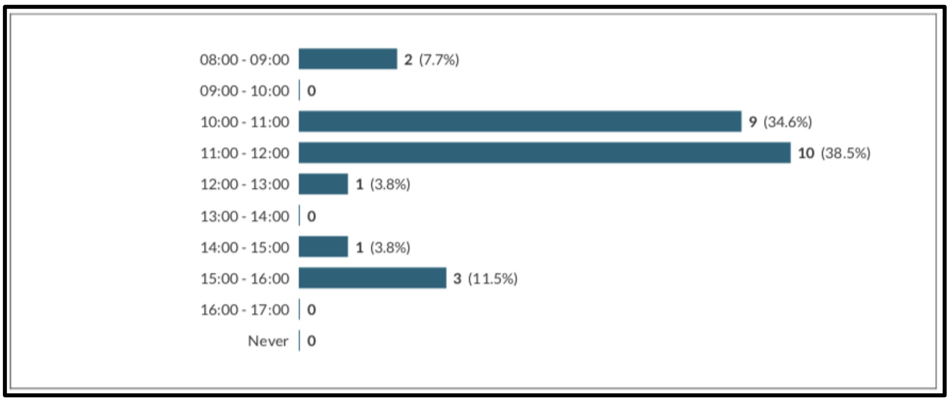


5Plus

Fig. 58 - Q23 - Considering we spend 75% of conscious time at work during the week, how would you rate your perceived overall feeling of satisfaction and/or feeling of well-being?

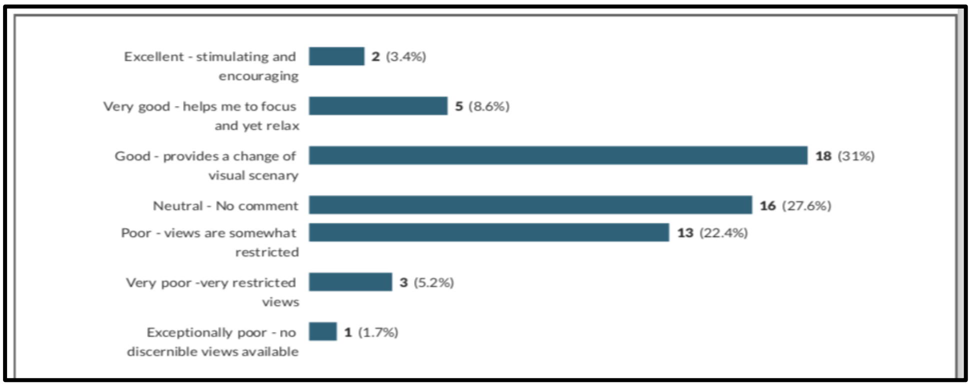


BSRIA

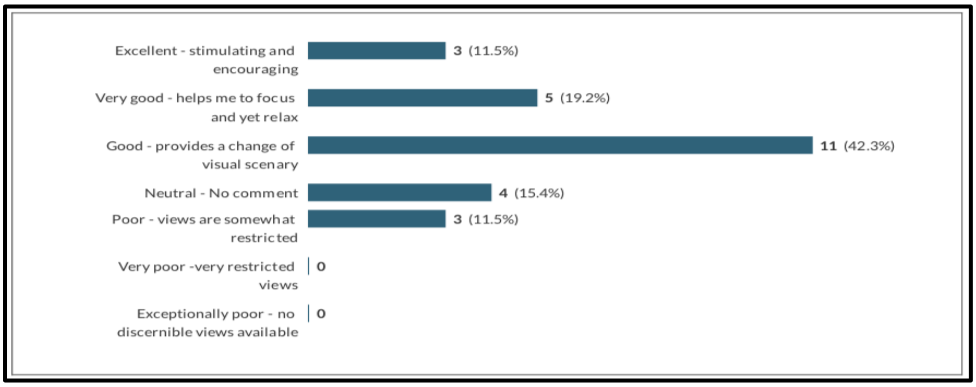


5Plus

Fig. 59 - Q24 - At what time of the working day would you generally say you reach your maximum level of performance?



BSRIA



5Plus

Fig. 60 - Q25 - How would you rate the overall vista or views provided within your office, and externally from your desk position?

The following Tables. 39 & 40 indicate the issues recorded by certain respondents across (Q14) - IEQ impacts across BSRIA and 5Plus Architects. Despite the (x2) number of respondents at BSRIA there is clearly issues which need to be addressed to improve workplace performance.

Noise and temperature too cold
Occasional too much noise Too hot in July
Some artwork on the walls will be nice. Also, using jazzy colours in kitchen areas would be nice.
Work colleagues and visitors complaining of cold
Just getting used to focusing without pin-drop silence!
sometimes a little noisy with people walking past my desk
noise distraction by other office workers
Too cold to concentrate on some days
Lack of any air movement creates a poor working environment
It can get far too cold in the office so I spend more time trying to figure out how to get warm then I do trying to work. As I sit in an office next to a café some of the smells from the microwave can be unpleasant so I end up distracted/disgusted by that. Likewise the noise can be too loud at times when there are events on.
Noise from other staff and unpleasant air quality from cigarette smoke contamination in AC system
Most days it gets very chilly. To the point that it becomes a distraction. Also sometimes causes headaches.
Office temperature is too cold for office workers who are sitting at their desks
Often distracted by being too cold
Too much clutter around. Tacky posters on walls in my eye-line. And whiteboards, etc. Used to tidy office with "empty desk policy"!
Sometimes too cold, draughty AC delivery above my workspace, cold meeting rooms, open plan noise disturbance, grubby carpets.
The air quality yesterday was not good, caused headache and dry eyes.
Temperature can be too hot or too cold. Distracting levels of noise both inside and outside the building.
Can be chilly, but that is because of the building structure, not the ventilation system
Less busy colleagues high volume noise talking and laughing. I am happy they are happy, but it's disturbing.
People speaking and laughing too loud
Noise from other people working/moving through area
Extremely warm and airless
temperature swings are too high, can be up to 10 deg c in summer/winter; gets stuffy - at times result in dry eyes and heavy head
Computer screen in front of window, blind has to be down to avoid eye strain

Table 39 - BSRIA Q14 comments

It's mainly to do with type of music playing in the background. It forced me to listen to my own playing device. I also suffer from an allergy to dust, the desk areas tend to by quite dusty.
Hard to answer. Stress levels aren't attributable to our environment. I do feel stress as part of my role.
Headaches
Concentration can be affected
The music!
Basic stress or work and deadlines

Table. 40 - 5Plus Q14 comments

4.5 Post Occupancy Survey Summary

Although limited to two sites and not achieving the desired survey responses (confidence level) the results of the survey are non the less interesting relative to the semi structured interviews and AHP survey responses.

General demographics are very similar across both sites and support a relatively sedentary work task orientated business. The age difference and time period employed does vary but this is seen as a result of the location of BSRIA and the inherent business nature of both sites. Both organisations are professional service related business and reflected an ideal base to conduct the research.

Despite the age of the buildings at BSRIA the overall the feeling of well-being was seen to be good to excellent with 58% of respondents stating good. At 5Plus a modern NV building, well-being was noted as good to excellent with 42% of respondents stating good, 34% very good and 19% excellent. This can be deemed related to the more modern NV design, new services and general ergonomics of the office compared to BSRIA.

Environmental system preference Q10 responses were as expected with BSRIA (67%) preferring a mixed mode ventilation system due primarily to a poor preforming 1990’s environment. 5Plus given their pedigree for NV designs however, preferred a naturally ventilated space with 77% of respondents supporting this view.

Similar responses were obtained for thermal comfort Q11 with both sites preferring to be cool but not cold – BSRIA (38%) and 5Plus (46%). The demographics (male/female) at BSRIA support the responses of 33% preferring to be warm and a further 20% preferring to warm but not too warm. Similar responses were observed at 5Plus 23% and 11% respectively.

Indoor Air Quality (IAQ) was an interesting set of responses. BSRIA an organsiation fully supportive of promoting IAQ, provided 28% of responses who were unaware of the IAQ. This may be a consequence of no discernable difference, but interesting to compare to 5Plus with 62% of responses indicating a fresh clean and odour less environment am & pm. BSRIA responses were recorded at 38%. Overall the 5Plus environment appears to be preforming much better than BSRIA.

During the initial site acceptance surveys, it was noted both sites were extremely noisy but during certain times of the day relatively quiet. As expected similar results were obtained in respect to noise impacts Q13 with 41% of respondents at BSRIA and 46% at 5Plus stating minor –ve impacts but tolerable distraction. Following on this question theme Q14 asked a similar question relative to the holistic workplace environment again with similar results; BSRIA responses of 46% minor -ve impacts; 28% no discernable impact; 14% small +ve impact and 8% major +ve impact. At BSRIA the respective results were; 46% minor -ve impacts; 15% no discernable impact; 34% small +ve impact.

When asked over the last 2-weeks have any of the following IEQ issues affected your performance (Q15) BSRIA and 5 Plus were remarkably similar. The expected responses and rankings indicated thermal comfort; draughts; noise and lighting remain the main issues affecting building occupants. Air quality and odours being the next area of concern.

Fatigue and timing was an interesting result, with BSRIA stating 26% between 14:00-15:00 and 20% 15:00-16:00, and at 5Plus, similar results were noted with 29% between 14:00-15:00 and 22% 15:00-16:00.

As expected noting the design and layout of the individual spaces, day-lighting Q18 was considered good (34%), very good (50%) and exceptionally good (11%) at 5 Plus. At BSRIA the responses ranged from poor (20%), neutral – no comment (14%), good (24%), very good (34%) and exceptionally good (7%). The daylight and connection to external lighting was noted as very good at both sites.

Artificial lighting responses Q19 were as expected. The new dimmable lighting scheme at 5Plus was considered neutral no – comment (11%), good (50%), very good (19%) and exceptionally good (8%). At BSRIA the old lighting technology, luminaires and controls have had an impact with responses ranging from very poor (2%), poor (29%), neutral – no comment (20%), good (36%), very good (9%) and exceptionally good (3%).

Given both sites were naturally ventilated (N.V) Q21 – Air Quality responses indicated similarities. Even though the N.V design at 5Plus utilised modern operable windows, orientation assessments, Computer modeling (CFD) and adaptive shading technology, the range of responses were almost the same, however, clearly 5Plus was considered a better environment with 31% stating good, 42% stating very good and 15% stating exceptionally good quality. BSRIA responses were adequate 47%, good 26% and very good 12%.

Again the design of the respective office environments and supporting IEQ systems has affected the results. A change in question format (Q22) at BSRIA provided a response of 26% neutral with no sensation of air movement, with 5Plus responding 11% neutral. 5Plus ranged from very poor 4%; poor 14%, neutral 26%, good 35%, very good 31% and excellent 15%. BSRIA responses ranged from (Likert 1-9 scale) 1-9 low to high. In comparison the BSRIA responses can be assessed as; very poor 7%; poor 24%, neutral 26%, good 31%, very good 10% and excellent 2%.

A change in question format (Q23) concerning Well-being at BSRIA provided a response of 17% neutral, with 5Plus responding 4% neutral . 5Plus ranged from poor 4%, neutral 4%, good 34%, very good 50% and excellent 8%. BSRIA responses ranged from (Likert 1-9 scale) 2-9 low to high. In comparison the BSRIA responses can be assessed as; very poor 2%; poor 12%, neutral 17%, good 58%, very good 9% and excellent 2%.

At what time do you reach your maximum level of performance Q24 provided similar response profiles? BSRIA responses stated 38% between 10:00-11:00, with 5Plus stating 35% between 10:00-11:00 and 28% between 11:00-12:00. These figures clearly indicate a preference for morning were the individual may or may not be stimulated by the IEQ factors. As noted in Q16, fatigue seems to occur later in the day from 14:00 onwards so its is perhaps during this period when the IEQ factors need to be stimulated and for feedback more resiliently provided to the occupant.

Overall and despite the differences in age, design and location the responses provide a similar set of responses and expectations. The key aspects noted concern the typical recurring IEQ factors that constantly evade solutions, IAQ and its communication of awareness, and the knowledge that peak performance and fatigue occur generally in the morning and afternoon respectively. The application of IEQ technology and feedback to the occupant may therefore be a step forward in allowing this information to assist decision-making.

4.6 Analytic Hierarch Process (AHP) Analysis

The AHP methodology is descried within Chapter 3 - Research Methodology. Appendix C contains a sample survey response feedback sheet and Table 38 indicates the survey deployment (x29). The AHP survey was administered with responders' during the Semi-structured interview visits to enable any questions to be answered. There were no failed responses and all were 100% completed.

4.6.1 Analytic hierarchy process

The AHP method is essentially a multi-criteria decision-making method arranging factors for decision in a hierarchic structure (Saaty, 1987; 1990). Its processing procedures can be summarised into four steps: 1) define the problem; 2) specify the hierarchic structure of decision making; 3) construct the comparison matrices for the analytic hierarchy model; 4) determine the weighting factor of the priorities of all elements (Saaty, 2008). The objective problem is described by a mathematical matrix equation according to the structure of the analytic hierarchy model, while the elements in the matrices that delineate the specific information for the factors are calculated by pairwise comparisons of criteria (or factors). The magnitude of a pairwise comparison indicates how many times one element is more important than another and the values of the elements are scaled from 1 to 9 or their reciprocals.

A statistical consistency criterion, i.e. consistency ratio (CR) is used to judge whether the pairwise reciprocal comparison matrices in the AHP are acceptable or not thus helping to confirm the credibility of data processing.

4.6.2 Influence factors of POE for the office buildings

The data on occupants' subjective opinions of building performance in regard to four office buildings in the UK were collected via questionnaire surveys with a total number of 27 subjects. The occupants include persons with specific interests, such as staff, managers, customers or clients, visitors, owners, designers or maintenance teams of the buildings, etc. The four buildings are notated as BS, FP, HP and VE and the distribution of the subjects for each office building is illustrated in Figure 62.

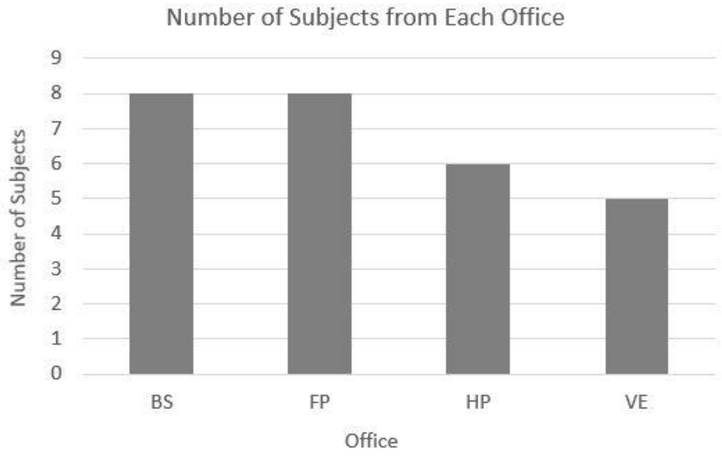


Fig. 62 - Numbers of subjects selected in each office building

The questionnaire surveys adopted the direct, unmediated subject matter expert experience of building occupants as the basis for evaluating how a building functions for its intended use. The respondents were asked individually to rank the importance of a series of sub-factors linking the POE of relevant buildings using the 9-point Likert scale. AN example question is provided below:

"Within the modern workplace how would you personally rank the importance of the building's HVAC system to recognise my presence and adjust to my pre-set personalised preferred thermal environment?"

Rating Scale								
Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

Table 41 - Nine-point Likert Scale definition

Within the questionnaires a total of 109 questions were ranked on the sheets but only the questions identified as key factors of the POE are retrieved from the database. The 109 questions in the survey corresponded to the points of the respondents' concern, while the questions related to the three main metrics were selected for a case study. Three metrics IEQ, Occupant Performance (OP) and Workplace Quality (WQ) were identified as the main factors linked to a couple of sub-factors individually for the POE. Namely, the factors associated with POE were categorised into a two-tier hierarchy. The key factors are listed in Table 43. The first two main factors (IEQ, OP) have five sub-factors each and the third one (WQ) has seven related sub-factors. The sub-factors of WQ contain the functions of buildings and the facilities in the experimental built environment. As the three main factors IEQ, OP and WQ interact and are intertwined with each other and they jointly affect the POE results of office buildings, it is interesting to explore the significance levels of the factors.

1	Indoor Environmental Quality (IEQ) Factors
1a	Lighting Quality (LQ).
1b	Indoor Air Quality (IAQ).
1c	Thermal Quality (TQ).
1d	Ventilation Quality (VQ).
1e	Noise Quality (NQ).
2	Occupant Performance (OP) Factors
2a	Incorporating blood oxygen levels into the HVAC ventilation strategy.
2b	Integrating occupant skin temperature to inform the BMS and HVAC systems.
2c	Understanding galvanic skin response (GSR) to inform the BMS and HVAC systems.
2d	Calculating and aggregating occupant metabolic rates to inform the BMS.
2e	Understanding occupant activity levels within the workplace to avoid a sedentary existence.
33a	Workplace Quality (WQ) Factors
3b	Sufficient work space so as not to feel over-crowded.
3c	The overall quality, comfort and style of the workplace furniture.
3d	Transition from outside the building to desk as easily as possible.
3e	The design and layout of the workplace in promoting a more effective and efficient working environment.
3f	Appropriate ICT systems to alleviate desktop components at the work-desk.
3g	Adequate social and amenity spaces.
3h	HVAC and building services as a major aspect of workplace design.

Table 42 – AHP Key Factors & Categories

4.6.3 AHP Structure the Office Buildings and Model

Fig. 63 gives the structure of the analytic hierarchy model for the POE associated with all the key factors identified in Table 4. The model has three levels to evaluate the workplace and occupant performance. The second level corresponds to the three main factors and the third level is constructed by the sub-factors related to each main factor. Notations A*i*, B*i*, C*i* are adopted for convenience. For instance, the workplace and occupant performance is noted as A1 and IEQ is represented by B1. The first group of sub-factors C1 to C5 is related to IEQ (B1). The second group C6-C10 is linked to OP (B2) and the third group C11 to C17 to WQ (B3).

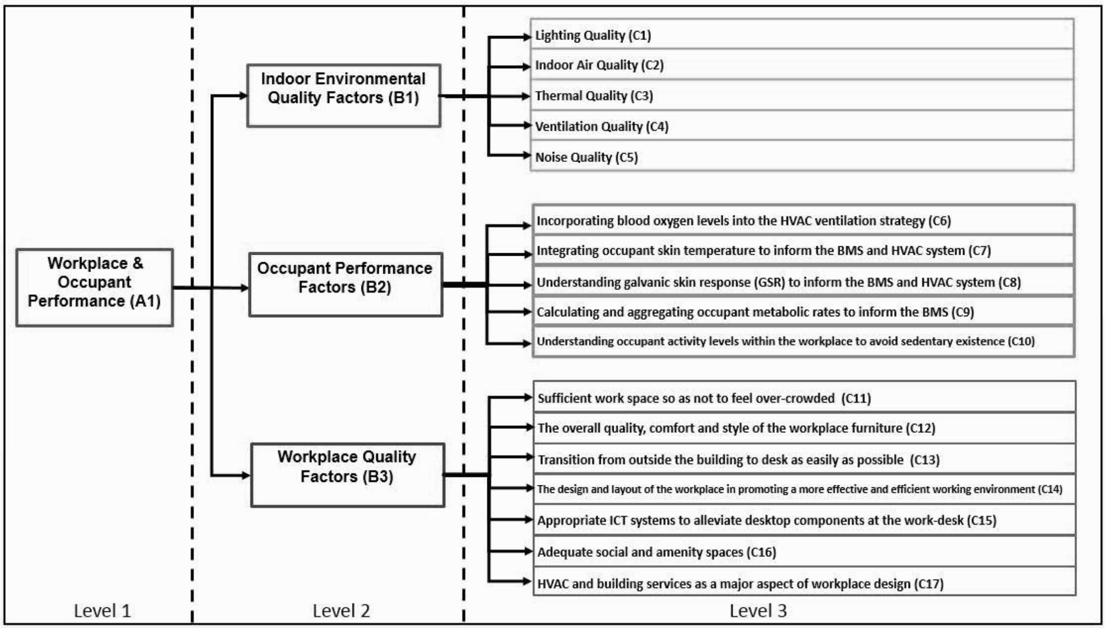


Fig. 63 - AHP Survey Framework (see survey template for further detail)

According to the AHP method and the structure of the AHP model in Fig.63 four comparison matrices concerning a group of the main factors and three groups of corresponding sub-factors can be generated based on the surveys. The comparison matrices represent the matrix of the three main factors, the matrix of the IEQ factors, the matrix of the OP factors and the matrix of WQ factors, respectively. Because each subject's opinion regarding the importance of each factor in the database is a magnitude based on the nine-point Likert scale, the pairwise comparisons between factors are firstly calculated. Once all the pairwise comparison matrices for the four groups of factors in relation to 27 subjects are calculated, they are combined using the AIJ method to generate four aggregated matrices of main factors (IEQ, OP and WQ).

Although it is presumed that the inherent nature of POE its purpose and methods are highly case-dependent, this makes it difficult to have a dominant standardized protocol for all the POE projects. Using buildings of the same type and SME responses, it is reasonable to treat the data collected from 29 subjects holistically.

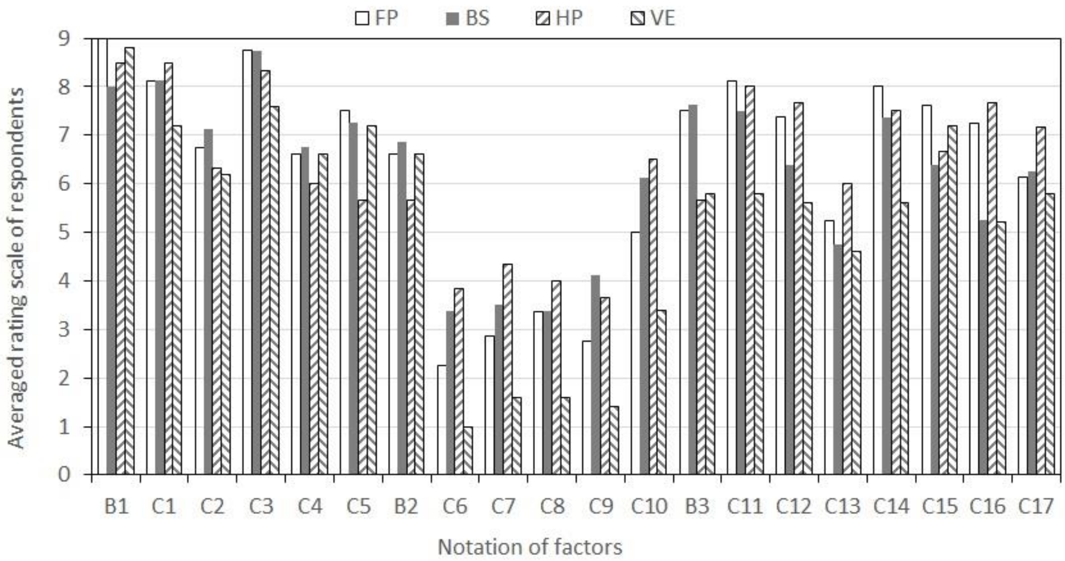


Fig. 64 - AHP Survey Respondent Rating Scale per Factor Category

Fig. 64 indicates the rating scales of respondents across the four sets of SME's and against each factor. For the four sets of SME's in question, the distributions tend to be similar, however, factors C6–C9 are seen to be lower than other factors. Using the original scaled response of the respondents, the pairwise comparison matrices on the two tiers of the hierarchic structure obtained as follows:

(1) Comparison matrix of B1, B2, B3 (n =3)

$$\begin{bmatrix} 1.0000 & 3.1812 & 2.7365 \\ 0.3143 & 1.0000 & 0.8108 \\ 0.3654 & 1.2334 & 1.0000 \end{bmatrix}$$

(2) Comparison matrix of C1–C5

$$\begin{bmatrix} 1.0000 & 2.1748 & 0.7785 & 2.2598 & 1.7507 \\ 0.4598 & 1.0000 & 0.3735 & 1.1200 & 0.8231 \\ 1.2846 & 2.6772 & 1.0000 & 2.7750 & 2.2401 \\ 0.4425 & 0.8928 & 0.3604 & 1.0000 & 0.7587 \\ 0.5712 & 1.2150 & 0.4464 & 1.3180 & 1.0000 \end{bmatrix}$$

(3) Comparison matrix of C6–C10

$$\begin{bmatrix} 1.0000 & 0.7395 & 0.7587 & 0.8022 & 0.3167 \\ 1.3523 & 1.0000 & 1.0527 & 1.0733 & 0.3750 \\ 1.3180 & 0.9500 & 1.0000 & 1.0532 & 0.3704 \\ 1.2466 & 0.9317 & 0.9495 & 1.0000 & 0.3506 \\ 3.1580 & 2.6663 & 2.6998 & 2.8523 & 1.0000 \end{bmatrix}$$

(4) Comparison matrix of C11–C17

$$\begin{bmatrix} 1.0000 & 1.4669 & 3.0590 & 1.1370 & 1.3122 & 1.6734 & 1.6479 \\ 0.6817 & 1.0000 & 2.3423 & 0.7669 & 0.8757 & 1.2704 & 1.1404 \\ 0.3269 & 0.4269 & 1.0000 & 0.3624 & 0.4189 & 0.5676 & 0.5687 \\ 0.8795 & 1.3040 & 2.7592 & 1.0000 & 1.1414 & 1.5242 & 1.5502 \\ 0.7621 & 1.1419 & 2.3870 & 0.8761 & 1.0000 & 1.3438 & 1.3543 \\ 0.5976 & 0.7872 & 1.7618 & 0.6561 & 0.7442 & 1.0000 & 0.9472 \\ 0.6068 & 0.8769 & 1.7583 & 0.6451 & 0.7384 & 1.0557 & 1.0000 \end{bmatrix}$$

Using the pairwise comparison matrices, the calculated weight factors are obtained (Table 44). It can be seen that on level two the IEQ (B1) has the highest priority factor of 0.595 compared to the other two main factors OP (B2) and WQ (B3), indicating that of the three main factors the IEQ is the major factor within the AHP survey. This weighting proposes IEQ factors are more important than the other two factors OP and WQ. The effects of factors OP and WQ are 0.183 and 0.222, respectively.

For the group of sub-factors affiliated to the IEQ, the sub-factor with the highest weighting factor is C3 (Thermal Quality), followed by C1 (Lighting Quality) with the second highest weighting factor. Regarding the group links to the OP, the sub-factor C10 (Understanding occupant activity levels within the workplace to avoid a sedentary existence) has the highest weighting factor of 0.414. When it comes to the group of WQ factors, the most important sub-factor is C11 (Sufficient work space so as not to feel over-crowded). It is also noteworthy that the least important sub-factor in the group is C13 (Transition from outside the building to desk as easily as possible).

Main factors label	Main Factors local/global Weights	Sub-factor Label	Sub-factor Local Weights	Sub-factor Global Weights
B1 (IEQ)	0.595	C1	0.267	0.159
		C2	0.126	0.075
		C3	0.337	0.201
		C4	0.117	0.070
		C5	0.153	0.091
B2 (OP)	0.183	C6	0.122	0.022
		C7	0.161	0.029
		C8	0.156	0.029
		C9	0.149	0.027
		C10	0.414	0.076
B3 (WQ)	0.222	C11	0.205	0.046
		C12	0.144	0.032
		C13	0.066	0.015
		C14	0.184	0.041
		C15	0.161	0.036
		C16	0.118	0.026
		C17	0.122	0.027

Table 43 - Local & Global Priority Factors of the AHP Structure

In order to satisfy consistency of results, CR values must be <0.1, supporting the consistency levels of the pairwise comparison matrices are acceptable and the data analysis is convincing.

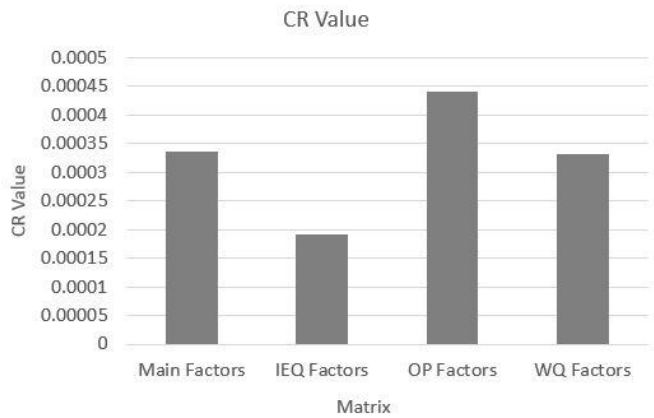


Fig. 65 - The consistency ratio of the pairwise comparison matrices

To further ascertain the importance levels of all the sub-factors related to the three main factors from the perspective of global comparison, the global weighting factors are calculated by the local weighting factors of the hierarchic structure in Fig. 66. The result is listed in Table 5. It can be found that among all the sub-factors, C3 (Thermal Quality) has the highest weighting factor (0.201), followed by C1 (Lighting Quality) with a weighting factor of 0.159. The global weighting factors of the others are below

0.1. This indicates that thermal quality and lighting quality are the two most significant sub-factors amongst all the sub-factors. Besides, the weight of C13 (Transition from outside the building to desk as easily as possible) is the smallest. The global weighting factors represent corresponding priorities of relevant influence factors, it will provide useful reference for organising questionnaire survey and investing physical measurement in the further development of POE.

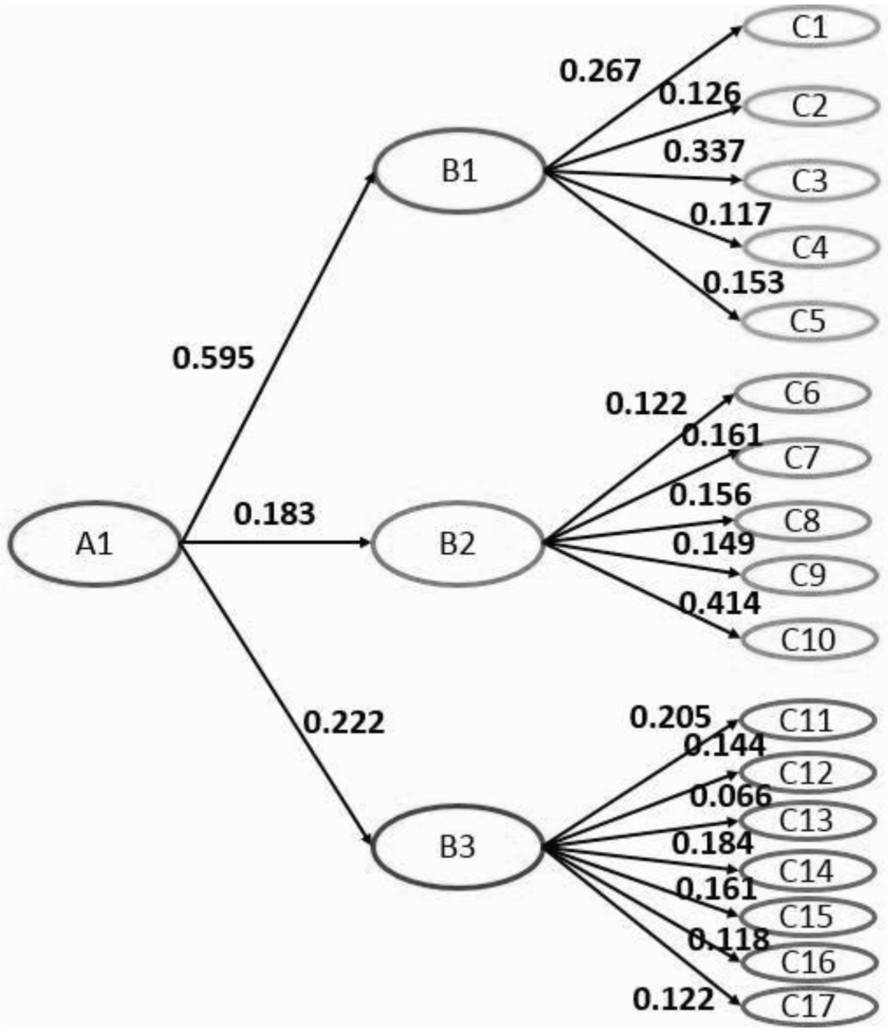


Fig. 66 - AHP Global Calculated Weighted Value per Factor Category

4.6.4 Analytic Hierarchy Process (AHP) Summary

The factors of the three main evaluation metrics, IEQ, OP, WQ are 0.595, 0.183 and 0.222, indicating that of the three factors the IEQ is the major factor. The global priorities of all the sub-factors linked to the main factors, thermal quality and lighting quality are identified as the two most significant sub-factors according to the results. Occupants' activity within the workplace to avoid a sedentary existence would appear to be the most important OP factor to be monitored. The most significant sub-factor relevant to WQ would appear to be sufficient workspace so as not to feel over-crowded.

This part of the research can be assumed a preliminary study given the limited number of respondents, however, the output would appear consistent across the semi-structured interview and on-line POE responses. Using two different qualitative methods and one mathematical quantitative technique has proven the general perceptions of SME's and occupants to be similar in comprehension. What is important is to understand within this research, is the premise that connecting people to the building is a core aim and by understanding the priorities occupants place on various factors will assist in providing this connectivity. Interesting the OP factors have scored consistently lower in importance again consistent with the qualitative surveys results. This research proposes that IEQ factors should be significantly promoted as a future performance need, to allow occupants to understand IEQ factors and their affects.

Chapter 5 – Sensory Monitoring

5.1 Introduction

This chapter presents and discusses the results of the physiological measurements derived from the Sensewear armbands worm by each (x8) volunteer, and the Hidalgo sensory vest worn by the research engineer (RE). The measured values have been tabulated to facilitate a comparative analysis between individuals and both research sites located at BSRIA (Bracknell) and 5Plus Architects (Manchester).

The Sensewear armbands provided (x28) individual measured and recorded parameters, however, this research selected seven (7) specific parameters to comparatively assess as detailed within Table 44.

Sensewear Armband Measured Parameters		
Measured Parameter	Units	Description
Skin Temperature	(deg.C)	Temperature of the skin directly under the armband contact points – Linear relationship to core temperature subject to environmental conditions.
Near Body Temperature	(deg.C)	Measures air temperature on the cover side of the armband.
Average Heat Flux	$(W \cdot m^{-2})$	Heat flux. Heat flux or thermal flux, sometimes also referred to as heat flux **density** or heat flow rate intensity is a flow of **energy** per unit of area per unit of time. In SI its units are watts per square **metre**.
Galvanic Skin Response	Micro Siemens (μS)	Electrical conductivity across 2-points of the skin. Affected by sweat and emotional stimuli measuring sweat rates.
Energy Expended	(kJ)	Energy expended as a consequence of thermal exchange and ambulatory activity.
Metabolic Equivalent	MET (kcal/kg/hr)	The ratio of the work metabolic rate to the resting metabolic rate. One MET is defined as equivalent to the energy cost of sitting quietly. A MET is the ratio of the rate of energy expended during an activity to the rate of energy expended at rest.
Activity (steps)	(No.)	Measures the ambulatory activity by counting the amount of steps within the period is worn.

Table 44 - Selected Sensewear Measured Parameters

5.2 Data Analysis Overview

The Sensewear armband was worn on the left arm throughout the day (only) with each individual parameter measured and time stamped on a day/minute period setting. A total of 444,409 individual readings were recorded and analysed under this review as scheduled below within Table 45.

<table>
<tr><th colspan="6">Individual Sensewear Measured Readings</th></tr>
<tr><th>Site</th><th>Individual</th><th>Individual Total</th><th>Site Total</th><th>Total (x7) parameters</th><th>Total (x7) Measured Parameters</th></tr>
<tr><td rowspan="4">5Plus Architects</td><td>CH</td><td>10,419</td><td rowspan="4">34,707</td><td rowspan="4">242,949</td><td rowspan="9">444,409</td></tr>
<tr><td>MH</td><td>6,828</td></tr>
<tr><td>MHar</td><td>8,338</td></tr>
<tr><td>RB</td><td>9,122</td></tr>
<tr><td rowspan="5">BSRIA</td><td>DD</td><td>4,286</td><td rowspan="5">28,780</td><td rowspan="5">201,460</td></tr>
<tr><td>SD</td><td>8,377</td></tr>
<tr><td>IW</td><td>5,547</td></tr>
<tr><td>MAH</td><td>8,579</td></tr>
<tr><td>SB</td><td>1,991</td></tr>
</table>

Table 45 – Total Measured Site Readings

The data was downloaded from each individual armband post each weeks site visit using the proprietary supplied software (Sensewear Professional 8.1). A data screen sample is provided within Fig. 66 Once downloaded into the proprietary software, the data was exported as an Excel (xls) file transfer and data cleansed. Data cleansing was a manual process for each line of data to remove any corrupted data, incorrect time stamps and/or data errors. Once cleansed the individual volunteer data was configured into overall base data, subject volunteer information, summary information and graphical data based upon the cleansed data from within the exported xls file. Graphical representation is also provided for each individual for each day and as a weekly summary.

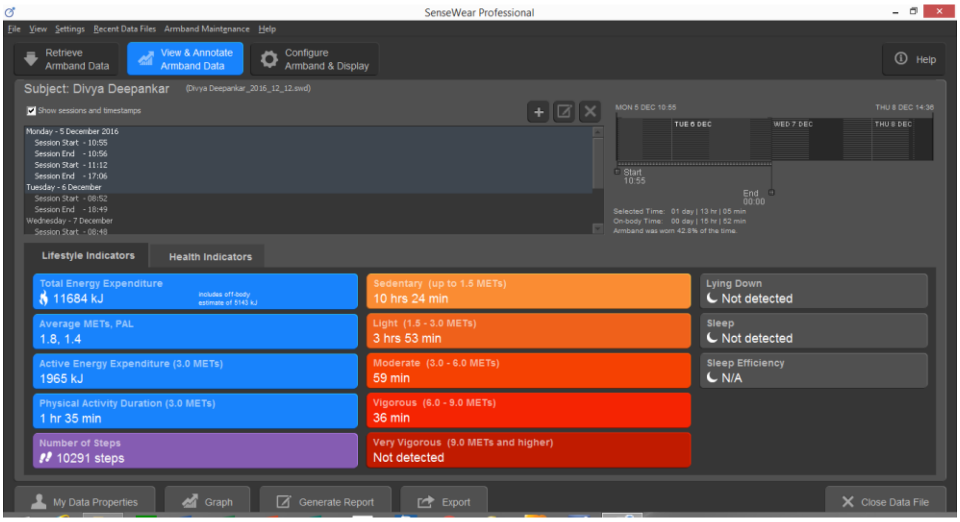


Fig. 66 – Sensewear Professional 8.1 Screen View

The data is analysed using descriptive statistics and tabulated to assess average, min, max, mode, variance and standard deviation values of each data set. The individual data was summarised for each individual volunteer, then as a research site and subsequently each site compared against each other across the selected (x7) measured parameters. A further data summary was completed to compare the daily, weekly and seasonal measured parameters and these are presented for each individual and for each site.

In addition to the Sensewear armband a Hidalgo sensory measuring vest is also summarised Table 67. The vest was worn by the research engineer within space due to the difficulty in obtaining data from the volunteers. The data provided from the vest was captured using the supplied proprietary software EqView Professional v4.1 with all live data saved and exported to Excel format for processing. The measured parameters are summarised within Table 46.

Hidalgo Vest Measured Parameters	
Description	Units
Heart Rate	Beats per minute – HR (bpm)
Breathing Rate	Breaths per minute – BR (rpm)
Blood Oxygen Level	Oxygen Saturtaion (%)
Skin Temperature	(deg.C)

Table 46 - Hidalgo Vest Measured Parameters (Research Engineer only)

This chapter therefore seeks to understand and to summarise the physiological performance of each individual within their respective site environment, and to understand theses key physiological variables to assess the potential for integrating measured data into building systems and architecture.

Chapter 7 (Discussion) will further summarise this chapter by reviewing the results across Chapters 4 & 6 to review if a relationship exists between perceived occupant feedback into what is seen as important to the occupant, and what is important to the designer and operator to enhance the long-term performance of the building and individual.

5.3 Experimental Methodology

Enabling both sites to be compared, the field investigation was conducted over a seasonal period across 2015 to 2016 at two locations in the UK. A description and layout for both sites was provided within Chapter 3 and both workplace tasks were extremely similar. The armband-wearing volunteers were assessed against an activity profile to select generally sedentary individuals and for attending the office the majority of the working day. None of the volunteers at either site location reported any discomfort or wearable issues with the armband and no data was considered unreliable once cleansed. The reliability of the device being proven under previous studies (Liu 2012).

The respective site volunteers as for example in previous studies, were not asked to complete any form of daily diary record, however, the R.E was in attendance day to day to assess the workplace and to maintain the functional operation of the armband and IEQ measuring devices. This approach was proven to guarantee the data collection and download so as not to corrupt or lose any data. The advantages of the Sensewear armband are (Tamas, Clements-Croome et al 2007) and (Wilson and Haglund 2003) they are easy to wear, simple to configure and use, suitable for prolonged use, very accurate data capture and relies only upon physiological responses without input from the surrounding environment.

Building occupant behaviours are time dependant (Yun and Steemers 2008) rather than static regular patterns, therefore it was essential to monitor each whole day and week were possible. This approach was used within previous study (Chen and Hwang 2011) who proposed that the magnitude of skin temperature changes were quicker and larger when a step change was experienced. This suggests that when the local ambient conditions altered, then so to would the human physiological heat balance. Previous research (Liu 2012) utilised a time depended sub stage approach divided into three discrete periods to understand these changes.

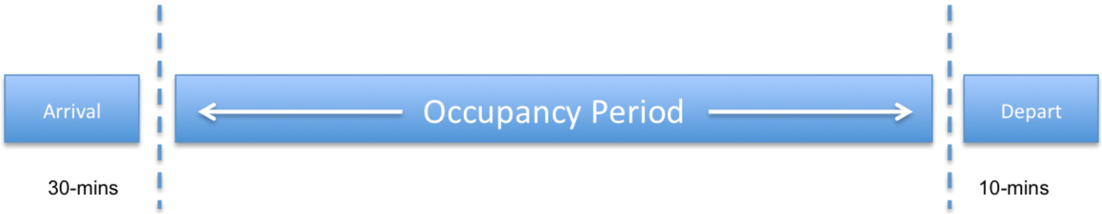


Fig. 67 – Three Stages of Occupancy.

The analysed data and graphical presentation for each volunteer under this research, focuses upon the total period the occupant is wearing the armband and in this instance does not segment time as indicated within Fig. 67.

5.4 Sensewear Armband – Measured Data & Analysis

At both research sites, (x4) volunteers were each inducted in wearing the armband and their personal details entered into the software. At 5Plus Architects (x1) volunteer was female and the remaining (x3) volunteers were male. At BSRIA (x1) volunteer was male and the remaining (x3) volunteers were female. During the (x4) 1-wk periods across Nov 15 to Dec 16 data was collected across the possible seasonal changes of Spring; Summer; Autumn; Winter.

The measured physiological date from each volunteer at both sites is tabulated to provide the following data:

- Day & date measured
- Volunteer Measured (Agent)
- Time per day the armband is worn
- Physiological parameters measured
- Total no of steps (activity level)

The following individual volunteer physiological data tables provide an average; maximum; minimum value inclusive of an assessment of variance and standard deviation for each day, week and season. A weekly seasonal set of values is calculated and a % average +/- deviation from the seasonal average calculated to assess where potential seasonal differences exist and to whether measured physiological factors would become acceptable feedback data to building management type systems.

5.4.1 5+ Architects Volunteer 1 (CH)

Table 47 indicates the measured data obtained from volunteer CH at 5Plus.. A non-smoking female of weight 58.5kg height 162.6cm and BMI of 22.1. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent. Volunteer CH was a consistent and excellent participant with a total armband on body time of 164hrs 39m (103%) from an expected research time of 160 hrs (8hrs/day x5days/wk x4 seasonal periods). The volunteer only missed 1-day out of the office 17/11/15 and therefore the data is considered sufficient for analysis.

The average skin temperature noted within Table 47 across spring, summer and autumn would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. The Weekly (Seasonal) Average Skin Temperature of 31.68 deg.C applied to each seasonal weekly average value indicates a 0.36% increase during Spring; 0.14% increase during Summer; 3.6% increase during Autumn; and -3.38% decrease during Winter. Across all x4 seasons Maximum figures range -0.06% winter to 5.98% autumn with Minimum figures ranging between -0.39% autumn to -8.3% during winter.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 29.37 deg.C applied to each seasonal weekly average value indicates a 0.08% increase during Spring; 0.33% increase during Summer; 2.95% increase during Autumn; and -2.78% decrease during Winter. Across all x4 seasons Maximum figures range 3.73% winter to 7.44% autumn with Minimum figures ranging between -0.44% spring to -16.31% during winter.

Heat flux average values although relatively consistent overall between the seasons the graphical representation would propose that this physiological measurement is not sufficiently accurate to use within a feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 81.99 W/m^2 applied to each seasonal weekly average value indicates a 5.89%% increase during Spring; -3.24% decrease during Summer; 12.37% increase during Autumn; and -12.52% decrease during Winter. Across all x4 seasons Maximum figures range -24.42% to 37.15% with Minimum figures ranging between -82.27% winter to 10.10% during summer.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (μS) of 5.33E-02 applied to each seasonal weekly average value indicates a -2.81% decrease during Spring; 7.48% increase during Summer; -8.75% decrease during Autumn; and 2.32% increase during Winter. Across all x4 seasons Maximum figures range -10.69% autumn to 144.65% summer with Minimum figures ranging between -24.00% summer/autumn/winter to 29.85% during spring.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 6.15 (KJ) applied to each seasonal weekly average value indicates a -5.77% decrease during Spring; 1.87% increase during Summer; -0.30% increase during Autumn; and 3.66% increase during Winter. Across all x4 seasons Maximum figures range -62.67% summer to 69.82% autumn with Minimum figures ranging between -21.17% winter to 17.95% during summer. The Weekly (Seasonal) Average Metabolic Equivalent value 1.53 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -2.07% decrease during Spring; 0.55% increase during Summer; 1.00% increase during Autumn; and 2.32% increase during winter. Across all x4 seasons Maximum figures range -65.40 summer to 57.41% autumn with Minimum figures ranging between -17.73% spring to 22.92% during summer. Step No.s are indicated only.

Sensewear Armband – Daily, Weekly & Seasonal Summary Data

Volunteer Agent – CH

5Plus Architects – Manchester – UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)					Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	14/03/16		6:24	31.22	32.13	29.25	0.18	0.42	28.83	30.04	26.80	0.28	0.53	84.23	125.69	50.93	173.76	13.18	5.72E-02	6.45E-02	8.79E-03	4.18E-05	6.47E-03	5.67	5.67	5.67	0.00	0.00	1.70	6.57	0.92	1.18	1.09	4,530
Tues	15/03/16		8:37	32.34	32.99	28.98	0.34	0.58	29.44	30.47	25.69	0.40	0.63	103.26	140.46	82.13	71.51	8.46	6.11E-02	7.47E-02	1.32E-02	8.05E-05	8.97E-03	5.88	27.94	3.93	11.34	3.37	1.44	6.85	0.96	0.68	0.83	2,722
Wed	16/03/16		9:30	31.75	32.68	28.22	0.44	0.66	29.28	30.77	25.95	0.79	0.89	87.29	151.42	33.95	445.29	21.10	5.21E-02	5.86E-02	1.25E-02	2.44E-05	4.94E-03	5.78	20.79	3.87	8.92	2.99	1.42	5.10	0.95	0.54	0.73	3,339
Thurs	17/03/16	CH	8:27	32.03	33.64	27.36	1.40	1.18	30.14	32.90	24.85	1.35	1.16	84.23	125.69	50.93	173.76	13.18	4.75E-02	6.08E-02	8.79E-03	8.34E-05	9.13E-03	5.67	5.67	5.67	0.00	0.00	1.36	3.12	0.91	0.07	0.27	675
Fri	18/03/16		8:23	31.66	33.53	28.51	0.62	0.79	29.30	31.42	25.48	0.81	0.90	75.12	164.51	18.15	323.05	17.97	4.11E-02	6.23E-02	1.10E-02	1.77E-05	4.21E-03	5.95	22.27	3.71	3.67	1.92	1.56	5.46	0.97	0.35	0.59	2,311
Week 1	**Spring**		**42:18**	**31.80**	**33.64**	**27.36**	**0.18**	**0.26**	**29.40**	**32.90**	**24.85**	**0.14**	**0.22**	**86.82**	**164.51**	**18.15**	**17,235.21**	**4.36**	**5.18E-02**	**7.47E-02**	**8.79E-03**	**7.61E-10**	**2.02E-03**	**5.79**	**27.94**	**3.71**	**21.43**	**1.43**	**1.49**	**6.85**	**0.91**	**0.14**	**0.27**	**2,715**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	13/07/15		8:57	32.16	33.23	28.30	0.59	0.77	29.86	30.92	25.58	0.73	0.86	81.51	81.51	81.51	81.51	81.51	6.77E-02	8.72E-02	1.25E-02	5.27E-05	7.26E-03	6.90	6.90	6.90	6.90	6.90	1.69	1.69	1.69	1.69	1.69	4,971
Tues	14/07/15		9:11	30.70	30.70	27.03	0.92	0.96	28.99	30.34	24.77	0.79	0.89	59.37	59.37	59.37	59.37	59.37	4.59E-02	7.69E-02	9.52E-03	2.26E-05	4.75E-03	5.78	5.78	5.78	5.78	5.78	1.42	1.42	1.42	1.42	1.42	1,063
Wed	15/07/15		8:44	30.59	31.69	28.15	0.48	0.69	28.50	30.11	24.97	0.85	0.92	73.20	73.20	73.20	73.20	73.20	5.16E-02	5.64E-02	1.17E-02	2.14E-05	4.62E-03	6.06	6.06	6.06	6.06	6.06	1.48	1.48	1.48	1.48	1.48	1,899
Thurs	16/07/15	CH	8:42	32.90	34.80	29.21	1.29	1.13	30.11	32.35	25.56	1.22	1.11	99.58	99.58	99.58	99.58	99.58	6.09E-02	1.77E-01	1.17E-02	5.51E-04	2.35E-02	7.03	7.03	7.03	7.03	7.03	1.72	1.72	1.72	1.72	1.72	4,874
Fri	17/07/15		5:45	32.30	32.94	28.60	0.45	0.67	29.91	30.69	25.91	0.36	0.60	85.19	85.19	85.19	85.19	85.19	6.03E-02	7.40E-02	9.52E-03	9.89E-05	9.94E-03	5.54	5.54	5.54	5.54	5.54	1.36	1.36	1.36	1.36	1.36	480
Week 2	**Summer**		**41:19**	**31.73**	**34.80**	**27.03**	**0.10**	**0.18**	**29.47**	**32.35**	**24.77**	**0.08**	**0.16**	**79.34**	**99.58**	**59.37**	**176.90**	**13.30**	**5.73E-02**	**1.77E-01**	**9.52E-03**	**4.11E-08**	**7.01E-03**	**6.26**	**7.03**	**5.54**	**0.36**	**0.60**	**1.53**	**1.72**	**1.36**	**0.02**	**0.15**	**2,657**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	16/11/15		8:13	33.08	34.52	30.13	1.06	1.03	30.76	32.21	26.72	1.23	1.11	82.98	172.58	38.18	697.44	26.41	5.88E-02	6.45E-02	3.88E-02	1.52E-05	5.88E-02	6.40	27.38	3.84	24.74	4.97	1.57	6.71	0.94	1.49	1.22	4,855
Tues	17/11/15		0:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wed	18/11/15		8:48	32.07	33.23	28.01	0.82	0.91	29.17	31.34	24.62	1.29	1.13	103.27	156.97	65.85	206.66	14.38	4.58E-02	6.23E-02	1.17E-02	3.46E-05	4.58E-02	6.32	31.96	3.88	18.62	4.32	1.55	7.83	0.95	1.12	1.06	3,557
Thurs	19/11/15	CH	9:59	32.85	34.11	29.23	0.87	0.93	30.88	33.46	26.80	1.23	1.11	70.15	173.09	20.17	431.04	20.76	4.84E-02	6.45E-02	9.52E-03	2.71E-05	4.84E-02	6.17	25.98	3.87	7.53	2.74	1.51	6.37	0.95	0.45	0.67	3,168
Fri	20/11/15		7:36	33.29	34.98	27.92	1.12	1.06	30.17	32.15	24.11	0.93	0.97	112.14	158.37	71.38	742.92	27.26	4.15E-02	5.06E-02	9.52E-03	2.40E-05	4.15E-02	5.78	26.98	3.87	8.35	2.89	1.42	6.61	0.95	0.50	0.71	1,691
Week 3	**Autumn**		**34:36**	**32.82**	**34.98**	**27.92**	**0.02**	**0.06**	**30.24**	**33.46**	**24.11**	**0.02**	**0.07**	**92.13**	**173.09**	**20.17**	**46,818.72**	**5.16**	**4.86E-02**	**6.45E-02**	**9.52E-03**	**4.81E-11**	**6.38E-03**	**6.16**	**31.96**	**3.84**	**51.99**	**0.94**	**1.51**	**7.83**	**0.94**	**0.19**	**0.23**	**3,318**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	12/12/16		9:20	30.98	32.79	28.47	0.51	0.71	28.27	29.98	24.85	0.71	0.85	95.54	180.71	64.61	316.41	17.79	7.53E-02	8.94E-02	1.32E-02	7.49E-05	8.65E-03	6.07	27.58	3.87	10.52	3.24	1.49	6.76	0.95	0.63	0.79	3,247
Tues	13/12/16		8:35	30.27	32.99	25.89	0.92	0.96	28.05	30.38	22.07	1.05	1.02	77.41	125.16	53.70	142.22	11.93	5.13E-02	6.59E-02	1.03E-02	4.36E-05	6.60E-03	6.15	25.96	4.03	6.23	2.49	1.51	6.36	0.99	0.37	0.61	2,026
Wed	14/12/16		9:08	29.86	31.32	26.88	0.37	0.61	27.95	29.15	24.36	0.63	0.80	66.00	172.70	36.80	408.26	20.21	5.10E-02	6.01E-02	1.25E-02	2.21E-05	4.70E-03	6.71	26.43	3.97	18.19	4.26	1.64	6.48	0.97	1.09	1.05	5,504
Thurs	15/12/16	CH	12:02	30.63	32.86	26.80	1.09	1.04	29.15	32.30	24.20	1.50	1.22	51.07	100.83	9.56	222.86	14.93	4.44E-02	5.28E-02	1.39E-02	1.32E-05	3.63E-03	6.57	26.16	3.75	15.60	3.95	1.61	6.41	0.92	0.94	0.97	6,732
Fri	16/12/16		7:21	31.33	32.04	25.71	0.42	0.65	29.37	30.71	20.89	0.91	0.95	68.60	156.33	29.26	201.19	14.18	5.06E-02	6.96E-02	9.52E-03	4.03E-05	6.35E-03	6.36	25.53	3.96	12.71	3.57	1.56	6.26	0.97	0.76	0.87	3,630
Week 4	**Winter**		**46:26**	**30.61**	**32.99**	**25.71**	**0.08**	**0.17**	**28.56**	**32.30**	**20.89**	**0.09**	**0.15**	**71.73**	**180.71**	**9.56**	**8,771.52**	**2.89**	**5.45E-02**	**8.94E-02**	**9.52E-03**	**4.52E-10**	**1.72E-03**	**6.37**	**27.58**	**3.75**	**17.05**	**0.61**	**1.56**	**6.76**	**0.92**	**0.06**	**0.15**	**4,228**
Weekly (Seasonal) Average Summary (x4 wks)			**5Plus (CH)**	**31.68**	**33.01**	**28.03**			**29.37**	**31.14**	**24.96**			**81.99**	**131.76**	**53.92**			**5.33E-02**	**7.22E-02**	**1.25E-02**			**6.15**	**18.82**	**4.70**			**1.53**	**4.98**	**1.10**			**3,230**

Seasonal Weekly % Average difference			Skin Avge	Skin Max	Skin Min	Near Body Avge	Near Body Max	Near Body Min	Heat Flux Avge	Heat Flux Max	Heat Flux Min	GSR Avge	GSR Max	GSR Min	Energy Avge	Energy Max	Energy Min	Metabolic Avge	Metabolic Max	Metabolic Min	Steps
Week 1	*Spring*	**5Plus (CH)**	0.36%	1.91%	-2.40%	0.08%	5.65%	-0.44%	5.89%	24.86%	-66.33%	-2.81%	3.52%	-29.85%	-5.77%	48.44%	-21.05%	-2.07%	37.59%	-17.73%	-15.92%
Week 2	*Summer*		0.14%	5.42%	-3.59%	0.33%	3.87%	-0.77%	-3.24%	-24.42%	10.10%	7.48%	144.65%	-24.00%	1.87%	-62.67%	17.95%	0.55%	-65.40%	22.92%	-17.72%
Week 3	*Autumn*		3.60%	5.98%	-0.39%	2.95%	7.44%	-3.38%	12.37%	31.37%	-62.60%	-8.75%	-10.69%	-24.00%	0.30%	69.82%	-18.12%	-1.00%	57.41%	-14.67%	2.73%
Week 4	*Winter*		-3.38%	-0.06%	-8.30%	-2.78%	3.73%	-16.31%	-12.52%	37.15%	-82.27%	2.32%	23.83%	-24.00%	3.66%	46.56%	-20.17%	2.32%	35.85%	-16.80%	30.91%

Abbreviations

Avge *Average mean value of all arguments*
Max *Maximum value within data set*
Min *Minimum value within data set*
Var *Variance from the average mean across the data set*
SD *Standard Deviation from the average mean value across the data set*
N/A *Volunteer Not Available*

Table 47 - Sensewear Armband Measured Values – Volunteer (CH)

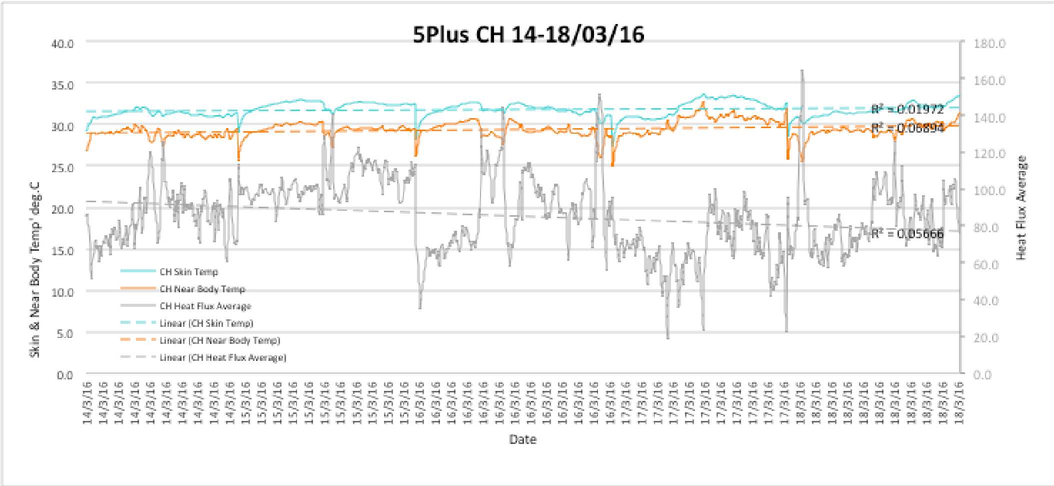


Fig. 68 – CH Seasonal Skin & Near Body Temperature and Heat Flux – March 2016 (Spring)

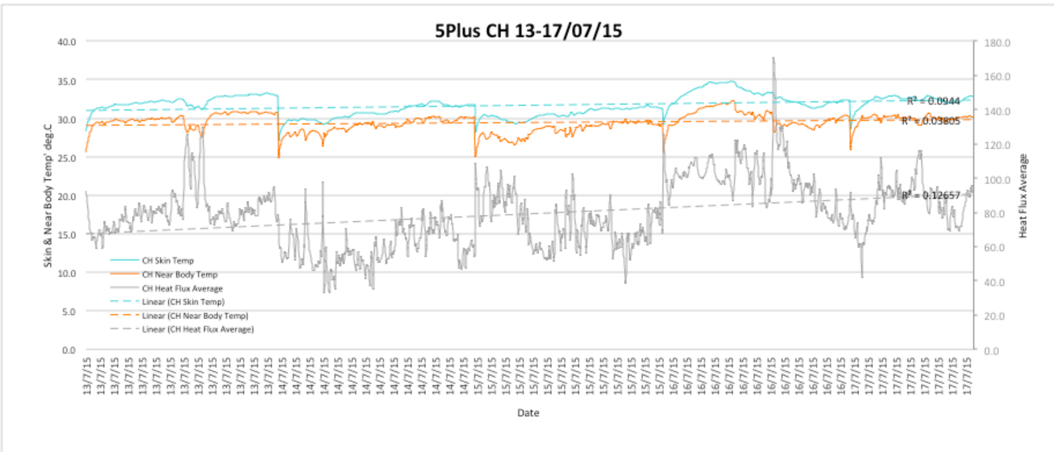


Fig. 69 – CH Seasonal Skin & Near Body Temperature and Heat Flux – July 15 (Summer)

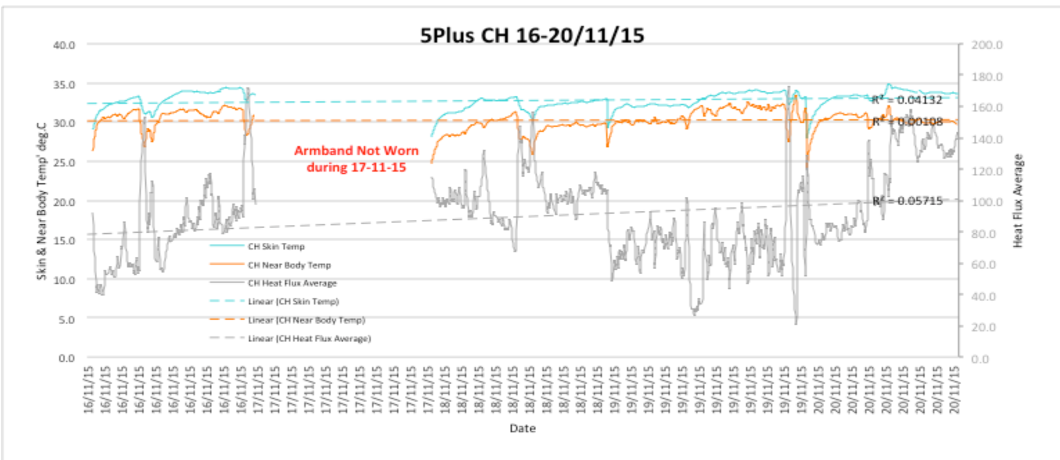


Fig. 70 – CH Seasonal Skin & Near Body Temperature and Heat Flux – November 2015 (Autumn)

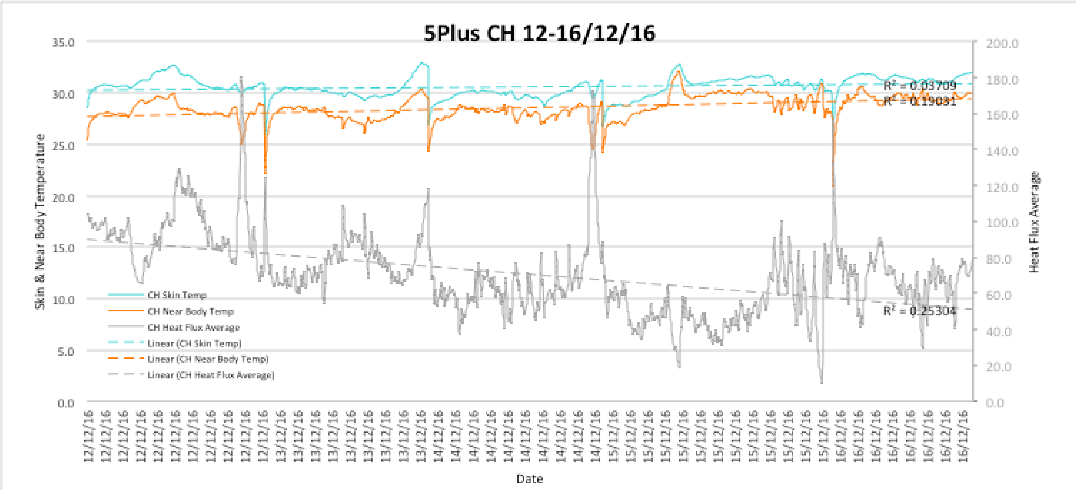


Fig. 71 – CH Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Fig's 68-71 represent the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 48. As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment.

Heat Flux average is a more variable set of values with greater R^2 and significant inclination of the trend line. Interestingly the winter and spring as contiguous transitional colder seasonal periods follow a downward heat flux trend over the weekly measured period, however, the summer and autumn periods indicating an upward trend. The summer and autumn trend is expected given these periods are generally warmer seasonal periods and where heat flux transfer can be expected to increase with ambient temperature and reduced clothing.

The following Fig's. 72-75 represents a daily assessment of Skin and Near Body temperature including Heat Flux average to offer a more granular level of detail across the same seasonal periods.

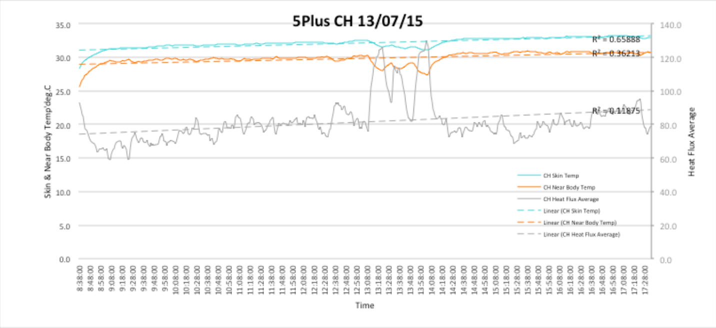
Key:

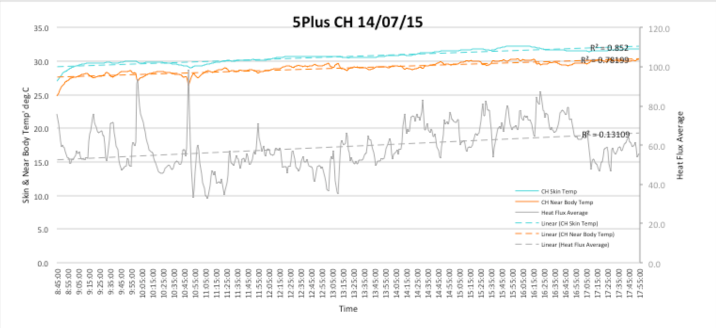
Skin Temperature

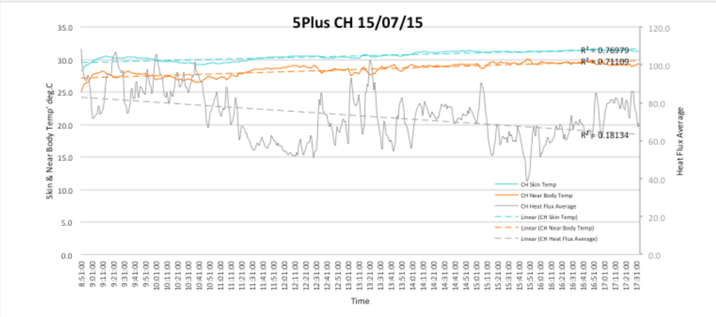
Near Body Temperature

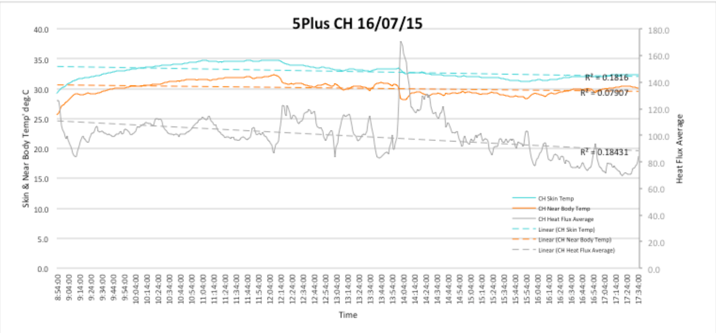
Heat Flux Average

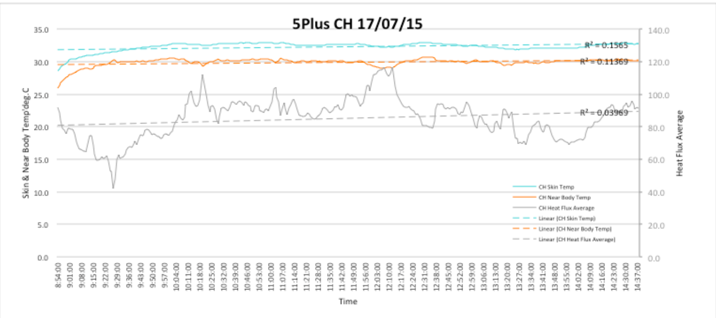
Fig. 72 – CH Daily Skin & Near Body Temperature and Heat Flux Values March 2016 (Spring)











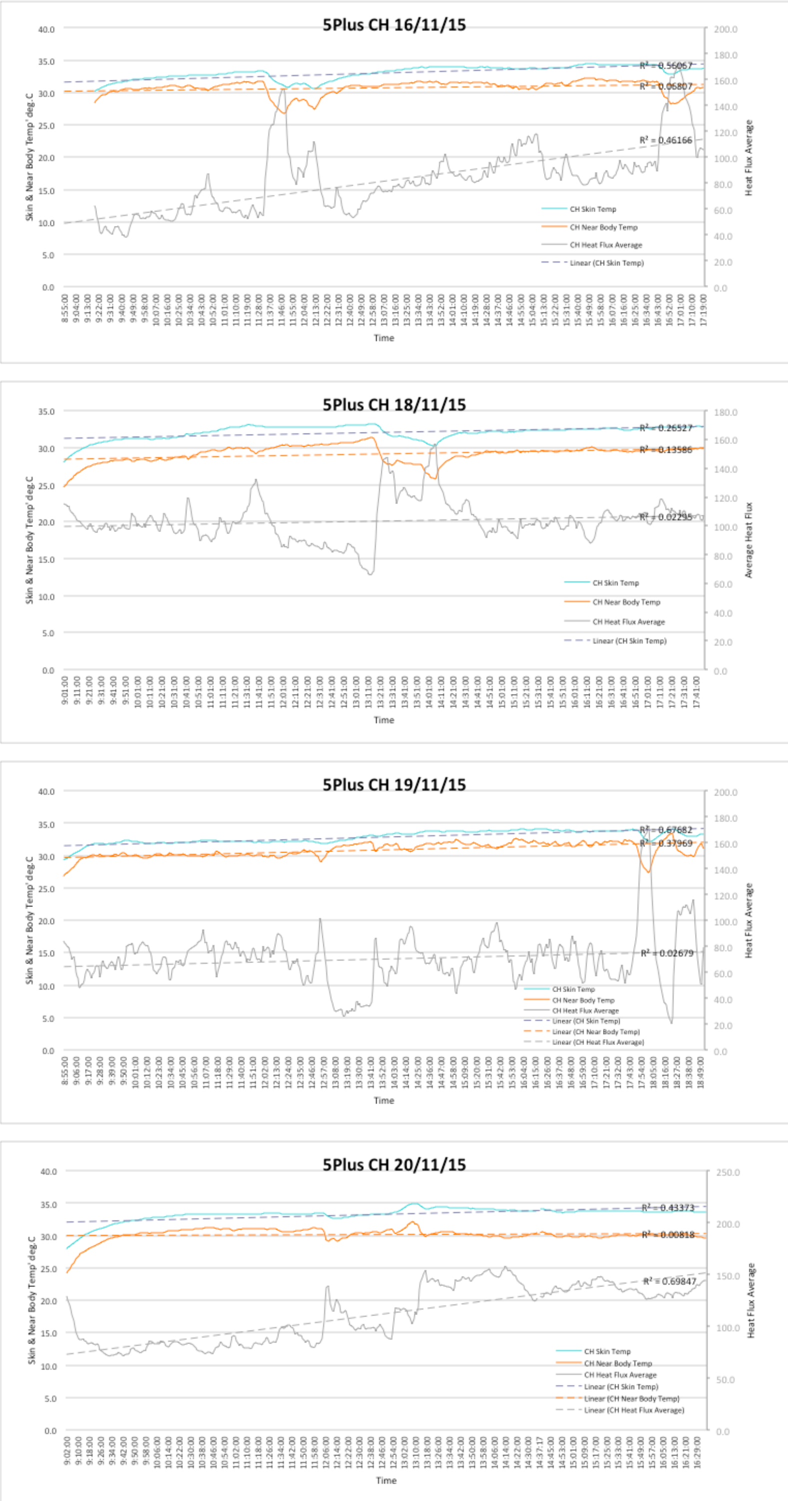
Key:

Skin Temperature

Near Body Temperature

Heat Flux Average

Fig. 73 – CH Daily Skin & Near Body Temperature and Heat Flux Values July 2015 (Summer)



Key:

Skin Temperature

Near Body Temperature

Heat Flux Average

Fig. 74 – CH Daily Skin & Near Body Temperature and Heat Flux Values November 2015 (Autumn)

Key:

Skin Temperature

Near Body Temperature

Heat Flux Average

Fig. 75 – CH Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

It is noted that the Skin and Near Body temperature rises continually throughout the day but within normal expected physical body temperature expectations. Heat flux average trends consistently upward during spring to autumn at varying degrees of R^2, yet downward during winter. Some correlation is noted between ambient parameters particularly around the lunchtime period, demonstrated by a sharp reduction or increase in both skin and/or near body temperature. This event driven period drives an opposite heat flux average response which is expected given a significant exchange in temperature is experienced by the individual going outside.

Fig's. 76-79 represents Galvanic Skin Response (GSR) across the seasonal equivalent periods. As the armband is worn on a daily basis, it is important note the sharp increase at the start of the day as the armband is worn, and the stress of arriving at work and settling down for the day ahead.

The overall weekly trend for volunteer (CH) during ***spring***, (Fig. 76) indicates a consistent downward trend (Mon-Fri), however, Thursday indicates the only daily increase in GSR during the afternoon period. The sharp increases in GSR being indicative of daily issues experienced either meetings or conflict situations and as yet not correlated to any IEQ factor. The weekly/daily response would appear typical of a normal expected GSR profile with sharp increase in the morning then reducing during the day subject to no additional stressors.

The overall weekly trend for volunteer (CH) during ***summer*** (Fig. 77) indicates a daily flat line GSR trend, however similar daily profile, but again Thursday has a significant GSR increase around lunchtime. Again the trend is a very slight reduction in GSR value Mon-Fri but not as progressive as indicated within the spring period. The sharp increase noted in GSR reflects a specifically stressful event, but is unclear as to its causation. It is concluded that a work related or lunchtime event occurred. The overall daily profile displayed a similar pre-morning shape to the spring period but less stress event orientated during each day.

The overall weekly trend for volunteer (CH) during ***autumn*** (Fig. 78) indicates a significantly progressive decrease in GSR and reflects a similar daily profile noted during the spring period. The volunteer missed one day as a result of taking the armband home, however, the overall trend and daily profiling would support the remaining measured values. The sharp increases at the beginning of the day support previous statements, with daily profiling indicating a number of similar increases and decreases at similar times of the day. Again as noted within the previous spring and summer periods, Thursday (pm) in particular seems to have increased GSR periods. This was reviewed with the volunteer and assessed as project review meeting stress.

The overall weekly trend for volunteer (CH) during ***winter*** (Fig. 79) again indicates a significant progressive reduction in GSR value over the period with similar daily profiles as previous seasonal periods spring & summer. The increase in GSR value during Fri was reviewed as having to complete work prior to the firms Christmas party to be held in the offices that evening.

Reviewing all of Volunteer (CH) GSR weekly profiles, the summer period only reflects a significant reduction in overall GSR value with the remaining seasonal periods indicating very similar profiling decreasing between Mon – Fri. Where higher GSR values are noted these were reviewed with the volunteer at the end of each week and assessed as work related stressors, however Chapter 6 reviews the possible relationship across air temperature, humidity and noise.

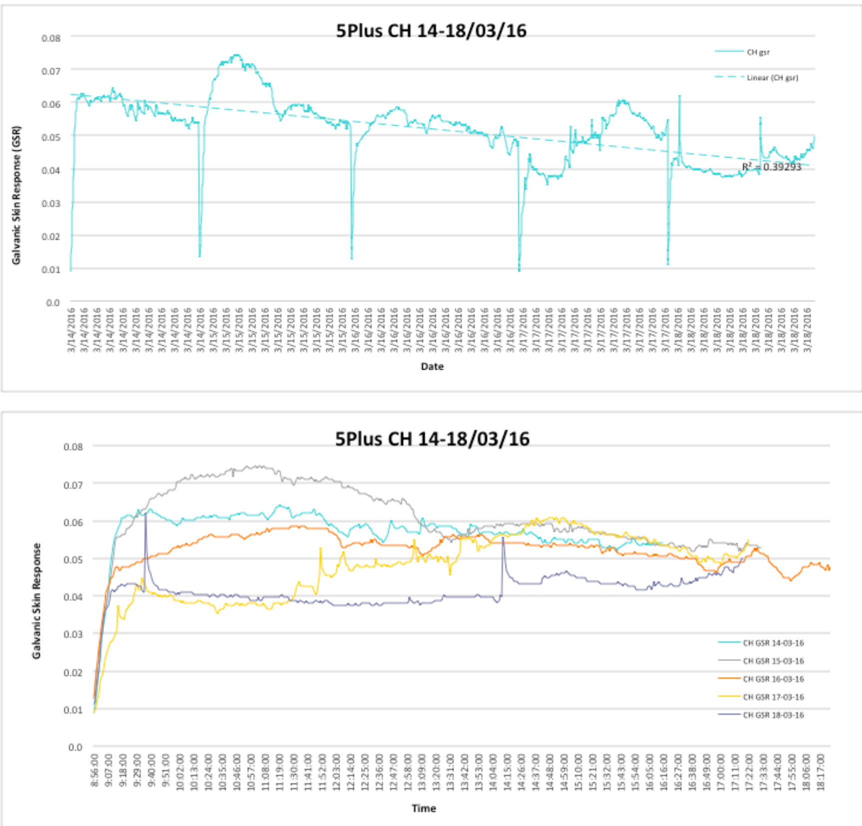


Fig. 76 – CH GSR Daily and Weekly Measured Values March 2016 (Spring)

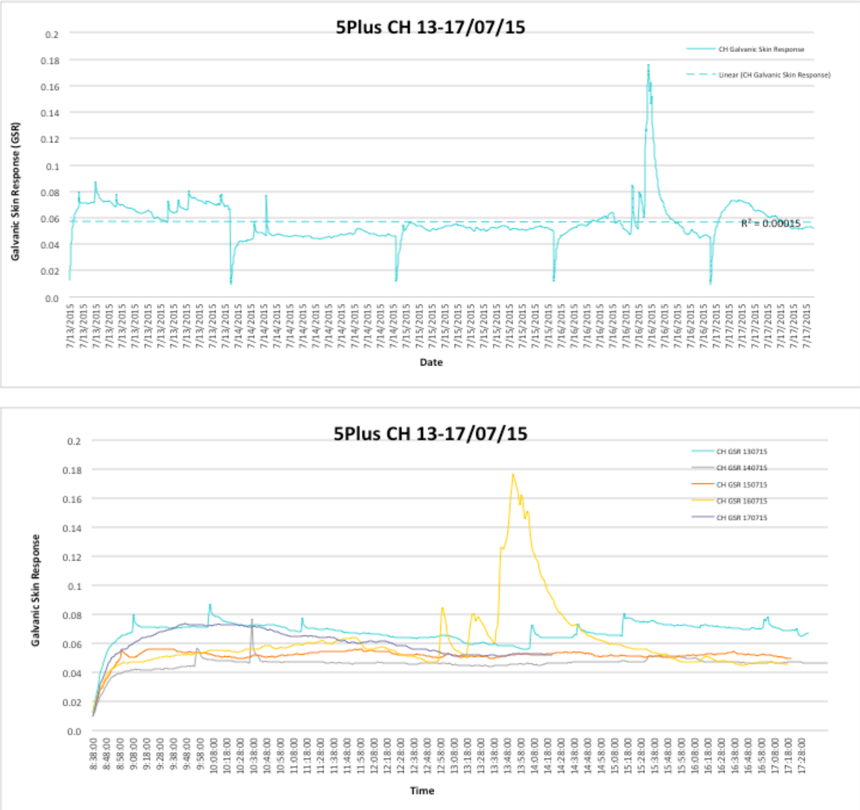


Fig. 77 CH – GSR Daily and Weekly Measured Values July 2015 (Summer)

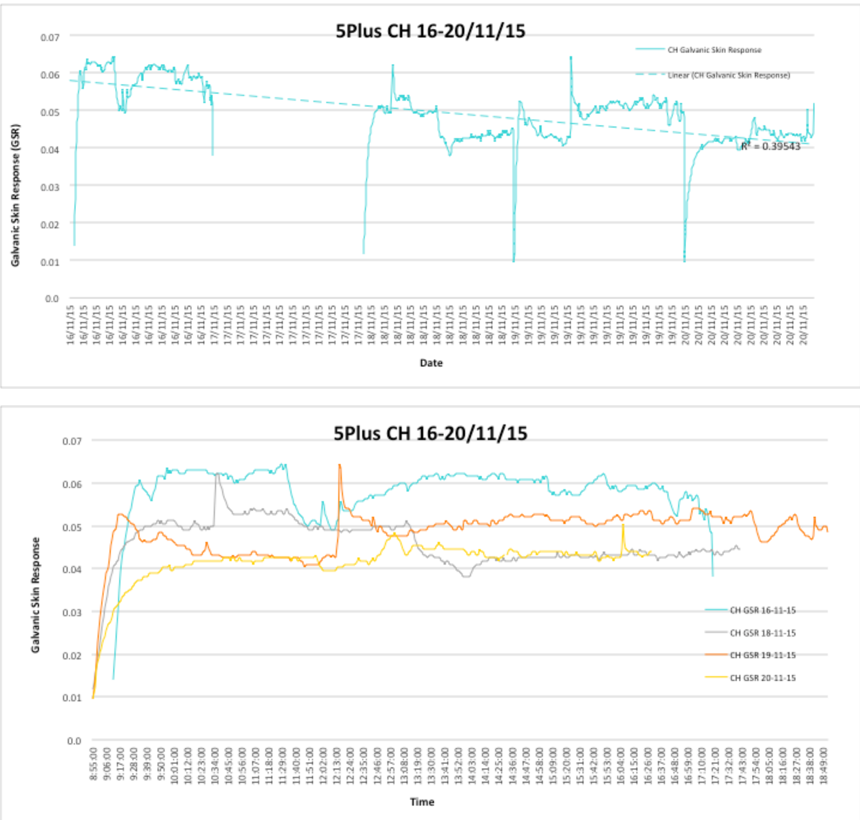


Fig. 78 CH – GSR Daily and Weekly Measured Values November 2015 (Autumn)

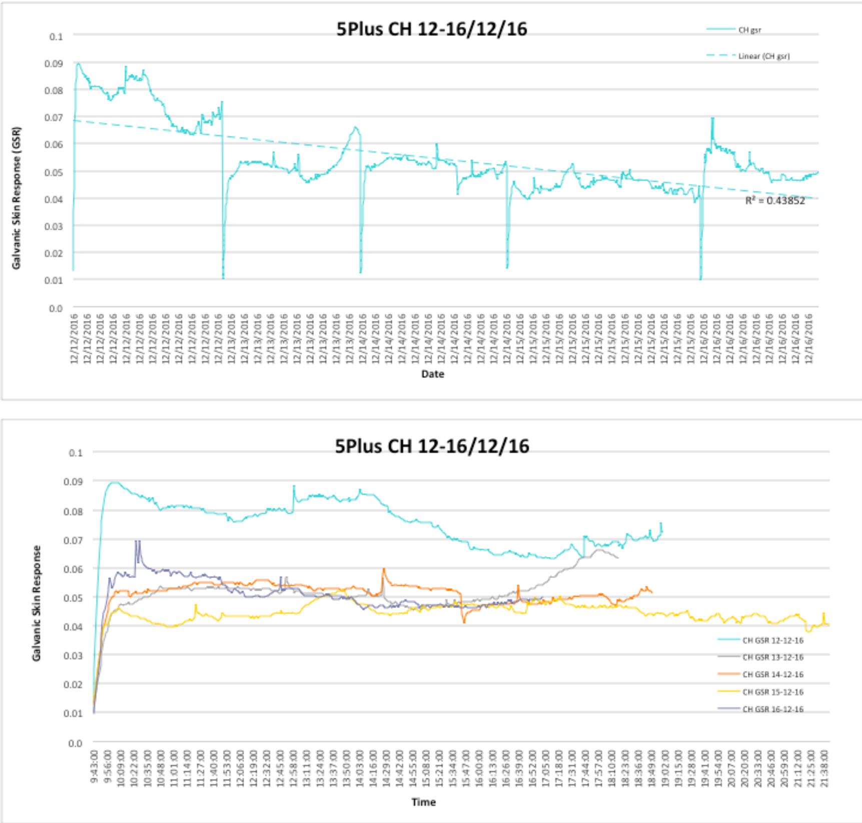


Fig. 79 CH – GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.2 5+ Architects Volunteer 1 (MHay)

Table 48 indicates the measured data obtained from volunteer MHay. A smoking male of weight 99.8kg height 177.8cm and BMI of 31.6 This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent. Volunteer MHay was a consistent and excellent participant with a total armband on body time of 123hrs 16mins (77%) from an expected research time of 160 hrs (8hrs/day x5days/wk x4 seasonal periods). The volunteer missed 4-days out of the office 15/03/16; 19-20/11/15; 12/12/16. The data is considered sufficient for analysis.

The average skin temperature noted within Table 48 across spring, summer, autumn and winter would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. The Weekly (Seasonal) Average Skin Temperature of 34.23 deg.C applied to each seasonal weekly average value indicates a 0.15% increase during Spring; -0.87% decrease during Summer; 0.0% increase/decrease during Autumn; and 0.93% increase during Winter. Across all x4 seasons Maximum figures range 0.63% autumn to 2.55% winter with Minimum figures ranging between -5.29% spring to 0.34% during summer.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 32.44 deg.C applied to each seasonal weekly average value indicates a 1.44% increase during Spring; -1.77% decrease during Summer; 0.35% increase during Autumn; and 0.52% increase during Winter. Across all x4 seasons Maximum figures range 3.35% winter to 1.61% spring with Minimum figures ranging between -0.08% autumn/winter to 0.02% during summer.

Heat flux average values although relatively consistent overall between the seasons would propose that this physiological measurement is not sufficiently accurate to use within any potential feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 64.11 W/m^2 applied to each seasonal weekly average value indicates a -24.36% decrease during Spring; 26.15% increase during Summer; -6.96% decrease during Autumn; and 8.22% increase during Winter. Across all x4 seasons' Maximum figures range –43.99% autumn to 48.79% winter with Minimum figures ranging between -122.12% spring to 58.63% during autumn.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (μS) of 1.14E-02 applied to each seasonal weekly average value indicates a 18.10% increase during Spring; -14.72% decrease during Summer; -6.16% decrease during Autumn; and 4.92% increase during Winter. Across all x4 seasons Maximum figures range -0.55% autumn to 128.03% summer with Minimum figures ranging between -81.35% spring to 57.69% during autumn.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 8.67 (KJ) applied to each seasonal weekly average value indicates a -1.55% decrease during Spring; -3.61% decrease during Summer; -2.05% increase during Autumn; and 4.53% increase during Winter. Across all x4 season's Maximum figures range 105.81% spring to -55.22% winter with Minimum figures ranging between -40.19% summer to 25.85% during winter The Weekly (Seasonal) Average Metabolic Equivalent value 1.26 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -2.79% decrease during Spring; -0.88% decrease during Summer; 0.91% increase during Autumn; and 3.21% increase during winter. Across all x4 season's Maximum figures range 3.31 summer to 65.59% autumn with Minimum figures ranging between -0.09% summer to -3.27% during summer. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteer Agent - MHay

5 Plus Architects - Manchester - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)					Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	14/03/16		7:10	34.89	35.56	28.64	0.50	0.71	33.36	34.64	25.15	0.89	0.94	54.50	132.14	17.22	150.89	54.50	2.24E-01	2.87E-01	4.25E-02	5.68E-04	2.38E-02	8.63	23.84	5.98	7.75	2.78	1.24	3.43	0.86	0.16	0.40	1,153
Tues	15/03/16		0:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wed	16/03/16		3:06	33.70	34.59	28.09	1.05	1.02	32.41	34.71	24.22	2.32	1.52	44.78	131.93	-6.62	497.69	44.78	1.32E-01	1.52E-01	3.37E-02	3.10E-04	1.76E-02	8.33	22.50	6.20	4.78	2.19	1.20	3.23	0.89	0.10	0.31	1,549
Thurs	17/03/16	MHay	8:33	34.18	35.07	29.98	0.49	0.70	32.88	34.23	26.63	0.90	0.95	45.50	116.80	13.68	217.91	45.50	1.04E-01	1.13E-01	1.69E-02	1.01E-04	1.01E-02	8.56	43.38	6.30	11.58	3.40	1.23	6.23	0.90	0.24	0.49	1,651
Fri	18/03/16		8:02	34.37	35.33	28.70	0.67	0.82	32.98	34.96	23.89	1.59	1.26	49.18	164.59	4.44	387.75	49.18	7.63E-02	9.23E-02	9.52E-03	6.50E-05	8.06E-03	8.62	24.45	5.98	6.56	2.56	1.24	3.51	0.86	0.14	0.37	1,372
Week 1	**Spring**		**26:51**	**34.28**	**35.56**	**28.09**	**0.05**	**0.13**	**32.91**	**34.96**	**23.89**	**0.34**	**0.24**	**48.49**	**164.59**	**-6.62**	**18,754.77**	**3.85**	**1.34E-01**	**2.87E-01**	**9.52E-03**	**4.01E-08**	**6.27E-03**	**8.53**	**43.38**	**5.98**	**6.22**	**0.44**	**1.23**	**6.23**	**0.86**	**0.00**	**0.06**	**1,431**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	13/07/15		9:17	34.26	35.51	29.91	0.47	0.69	33.05	35.24	26.70	1.08	1.04	42.25	116.88	6.21	243.82	15.61	1.19E-01	3.53E-01	2.71E-02	1.24E-03	3.51E-02	8.69	22.40	6.34	4.73	2.18	1.24	3.19	0.90	0.10	1.24	1,421
Tues	14/07/15		8:31	34.35	35.93	29.76	0.57	0.75	32.41	35.03	26.43	1.29	1.14	69.56	122.53	15.61	359.06	18.95	1.16E-01	1.62E-01	6.01E-02	7.33E-05	8.56E-03	8.50	22.06	6.01	4.10	2.03	1.21	3.14	0.86	0.08	1.21	770
Wed	15/07/15		3:16	34.35	34.91	30.54	0.33	0.57	32.05	33.28	25.99	0.99	0.99	82.78	159.34	55.17	310.28	17.61	1.16E-01	1.61E-01	4.18E-02	5.11E-04	2.26E-02	7.95	21.46	6.44	3.04	1.74	1.13	3.06	0.92	0.06	1.13	182
Thurs	16/07/15	MHay	6:51	33.49	34.09	29.78	0.25	0.50	30.91	32.52	26.16	0.59	0.77	88.23	135.45	43.79	145.45	12.06	5.21E-02	7.91E-02	2.05E-02	9.78E-05	9.89E-03	7.47	27.31	4.07	11.07	3.33	1.37	3.89	0.86	0.14	1.37	1,709
Fri	17/07/15		4:00	33.23	34.39	30.51	0.24	0.49	30.92	32.54	26.34	0.84	0.92	82.91	148.81	44.58	424.39	20.60	8.07E-02	1.22E-01	5.20E-02	2.72E-04	1.65E-02	9.16	21.69	6.54	3.29	1.81	1.30	3.09	0.93	0.07	1.30	449
Week 2	**Summer**		**41:19**	**33.94**	**35.93**	**29.76**	**0.02**	**0.10**	**31.87**	**35.24**	**25.99**	**0.06**	**0.12**	**80.87**	**159.34**	**6.21**	**9,209.57**	**2.95**	**9.68E-02**	**3.53E-01**	**2.05E-02**	**1.83E-07**	**9.70E-03**	**8.35**	**27.31**	**4.07**	**8.83**	**0.58**	**1.25**	**3.89**	**0.86**	**0.00**	**0.08**	**906**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	16/11/15		6:05	34.33	35.42	30.58	0.44	0.66	32.28	34.61	26.99	1.15	1.07	73.38	73.38	73.38	73.38	73.38	1.56E-01	1.56E-01	1.56E-01	1.56E-01	1.56E-01	8.84	22.28	6.26	5.78	2.41	1.27	3.20	0.90	0.12	0.35	993
Tues	17/11/15		8:33	34.14	35.14	30.56	0.48	0.69	32.78	35.26	26.84	1.37	1.17	47.50	47.50	47.50	47.50	47.50	8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.33E-02	8.53	22.21	6.15	4.24	2.06	1.23	3.19	0.88	0.09	0.30	791
Wed	18/11/15		8:43	34.23	35.47	28.70	0.53	0.73	32.59	34.84	23.44	1.28	1.13	58.05	58.05	58.05	58.05	58.05	8.05E-02	8.05E-02	8.05E-02	8.05E-02	8.05E-02	9.17	27.43	6.29	5.06	2.25	1.32	4.21	0.90	0.12	0.35	1,281
Thurs	19/11/15	MHay	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fri	20/11/15		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 3	**Autumn**		**23:21**	**34.23**	**35.47**	**28.70**	**0.00**	**0.03**	**32.55**	**35.26**	**23.44**	**0.01**	**0.04**	**59.64**	**73.38**	**47.50**	**112.90**	**10.63**	**1.07E-01**	**1.56E-01**	**8.05E-02**	**1.22E-03**	**3.49E-02**	**8.85**	**27.43**	**6.15**	**0.40**	**0.14**	**1.27**	**4.21**	**0.88**	**0.00**	**0.02**	**1,022**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	12/12/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tues	13/12/16		9:40	34.84	36.14	29.19	0.62	0.79	32.95	35.28	24.40	1.54	1.24	67.50	165.04	26.03	466.63	21.60	1.47E-01	2.13E-01	8.35E-02	2.09E-04	1.45E-02	9.35	9.35	9.35	9.35	9.35	1.34	4.58	0.86	0.30	0.55	2,301
Wed	14/12/16		8:23	34.70	35.93	30.13	0.85	0.92	33.28	35.56	25.58	2.17	1.47	49.83	158.65	7.10	650.18	25.50	1.09E-01	1.32E-01	1.17E-02	1.17E-04	1.08E-02	9.44	9.44	9.44	9.44	9.44	1.36	4.40	0.92	0.39	0.63	2,740
Thurs	15/12/16	MHay	6:41	34.90	35.63	30.00	0.41	0.64	32.68	34.20	25.11	1.08	1.04	79.47	170.12	37.54	280.57	16.75	1.06E-01	1.36E-01	1.98E-02	1.57E-04	1.25E-02	8.89	8.89	8.89	8.89	8.89	1.28	4.31	0.86	0.13	0.36	728
Fri	16/12/16		7:01	33.79	34.77	29.51	0.37	0.61	31.53	33.59	23.85	0.95	0.98	80.70	194.92	35.43	237.76	15.42	1.14E-01	1.59E-01	7.84E-02	1.37E-04	1.17E-02	8.56	8.56	8.56	8.56	8.56	1.23	3.57	0.86	0.11	0.33	661
Week 4	**Winter**		**31:45**	**34.55**	**36.14**	**29.19**	**0.04**	**0.12**	**32.61**	**35.56**	**23.85**	**0.23**	**0.19**	**69.37**	**194.92**	**7.10**	**26,826.08**	**4.01**	**1.19E-01**	**2.13E-01**	**1.17E-02**	**1.18E-09**	**1.35E-03**	**9.06**	**9.44**	**8.56**	**0.13**	**0.36**	**1.30**	**4.58**	**0.86**	**0.01**	**0.13**	**1,608**
Weekly (Seasonal) Average Summary (x4 wks)			**5 Plus (MHay)**	**34.23**	**35.24**	**29.66**			**32.44**	**34.41**	**25.48**			**64.11**	**131.01**	**29.94**			**1.14E-01**	**1.55E-01**	**5.11E-02**			**8.67**	**21.08**	**6.80**			**1.26**	**3.76**	**0.88**			**1,242**

Seasonal Weekly % Average difference																																		
Week 1	*Spring*			0.15%	0.90%	-5.29%			1.44%	1.61%	-0.06			-24.36%	25.6%	-122.1%			18.10%	84.95%	-81.35%			-1.55%	105.81%	-12.09%			-2.79%	65.59%	-2.92%			15.27%
Week 2	*Summer*		**5 Plus (MHay)**	-0.87%	1.95%	0.34%			-1.77%	2.41%	0.02			26.15%	21.6%	-79.3%			-14.72%	128.03%	-59.83%			-3.61%	29.57%	-40.19%			-0.88%	3.31%	-3.27%			-27.02%
Week 3	*Autumn*			0.00%	0.63%	-3.23%			0.35%	2.48%	-0.08			-6.96%	-44.0%	58.6%			-6.16%	0.55%	57.69%			2.05%	30.12%	-9.52%			0.91%	11.92%	-0.09%			-17.72%
Week 4	*Winter*			0.93%	2.55%	-1.59%			0.52%	3.35%	-0.06			8.22%	48.8%	-76.3%			4.92%	37.16%	-77.05%			4.53%	-55.22%	25.85%			3.21%	21.55%	-2.92%			29.46%

<u>Abbreviations</u>

Avge ***Average mean value of all arguments***
Max ***Maximum value within data set***
Min ***Minimum value within data set***
Var ***Variance from the average mean across the data set***
SD ***Standard Deviation from the average mean value across the data set***
N/A ***Volunteer Not Available***

Table 48 - Sensewear Armband Measured Values – Volunteer (MHay)

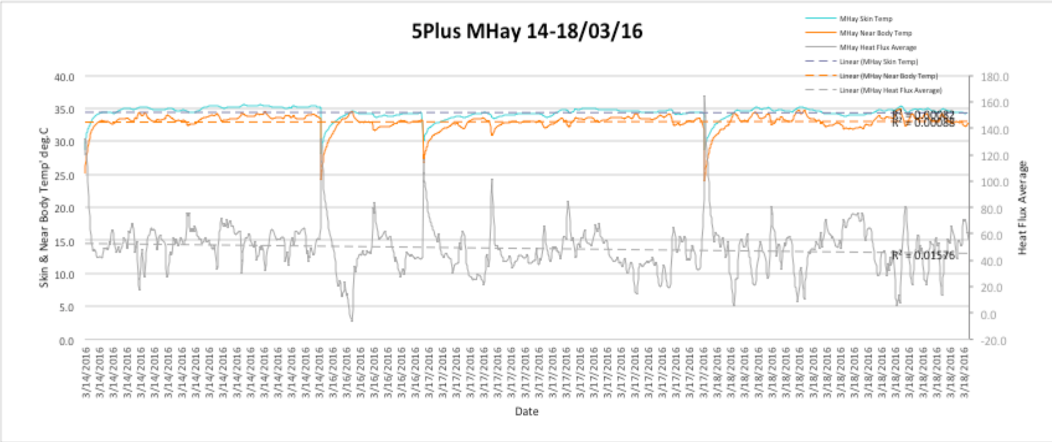


Fig . 80 – MHay Seasonal Skin & Near Body Temperature and Heat Flux – March 2016 (Spring)

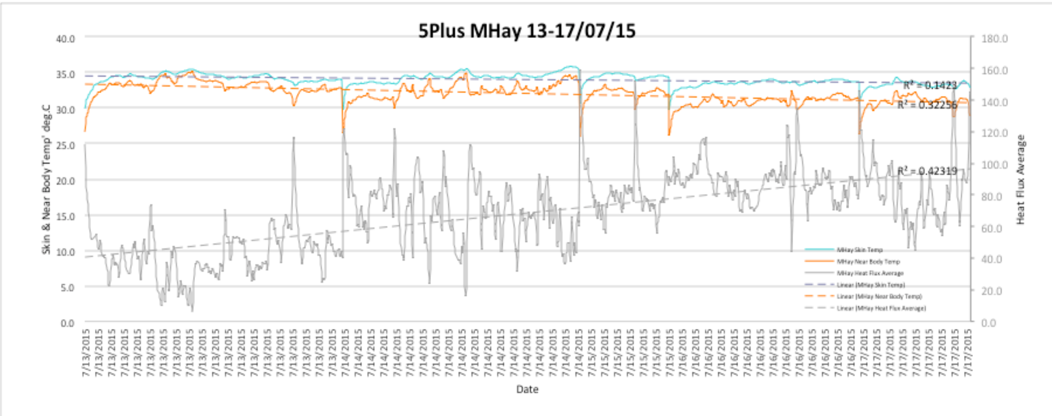


Fig. 81 – MHay Seasonal Skin & Near Body Temperature and Heat Flux – July 2015 (Summer)

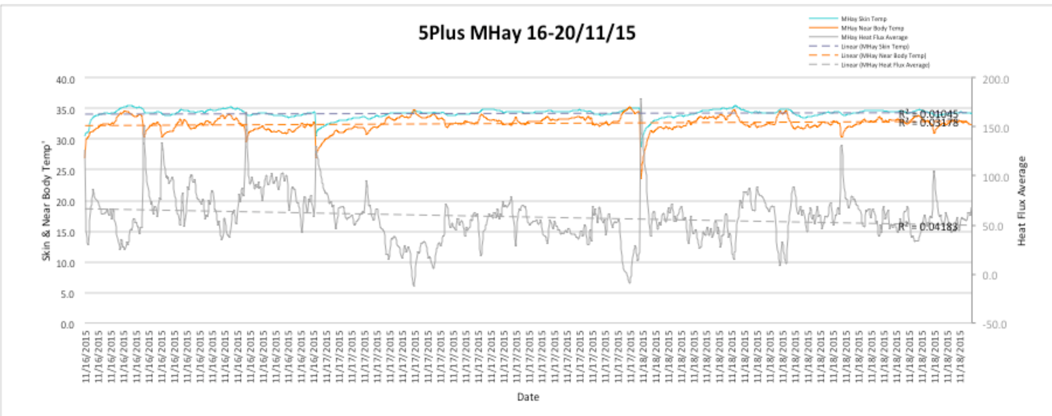


Fig. 82 – MHay Seasonal Skin & Near Body Temperature and Heat Flux – November 2015 (Autumn)

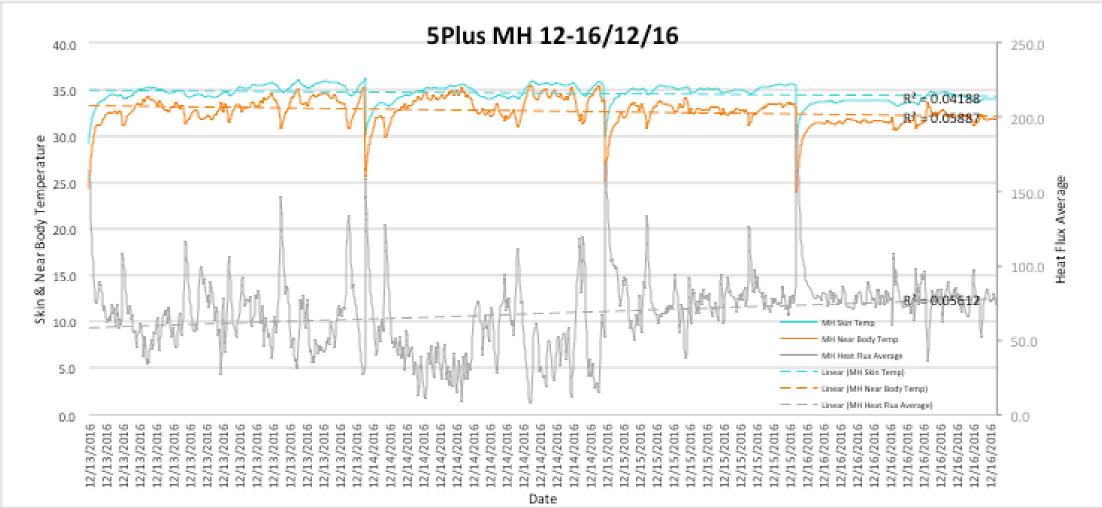


Fig.83 – MHay Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Fig's. 80-83 represents the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 49. As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier. Similar results were found with volunteer (CH)

Heat Flux average is a more variable set of values with greater R^2 values annd significant inclination of the trend line. Summer and winter periods indicate a increasing trend, however, spring and autumn indicate a slight decreasing trend. The summer and winter trend is not expected. The expectation that winter heat flux would be lower and a reducing trend is not supported from the measured values.

The following Fig's. 84-87 represents a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

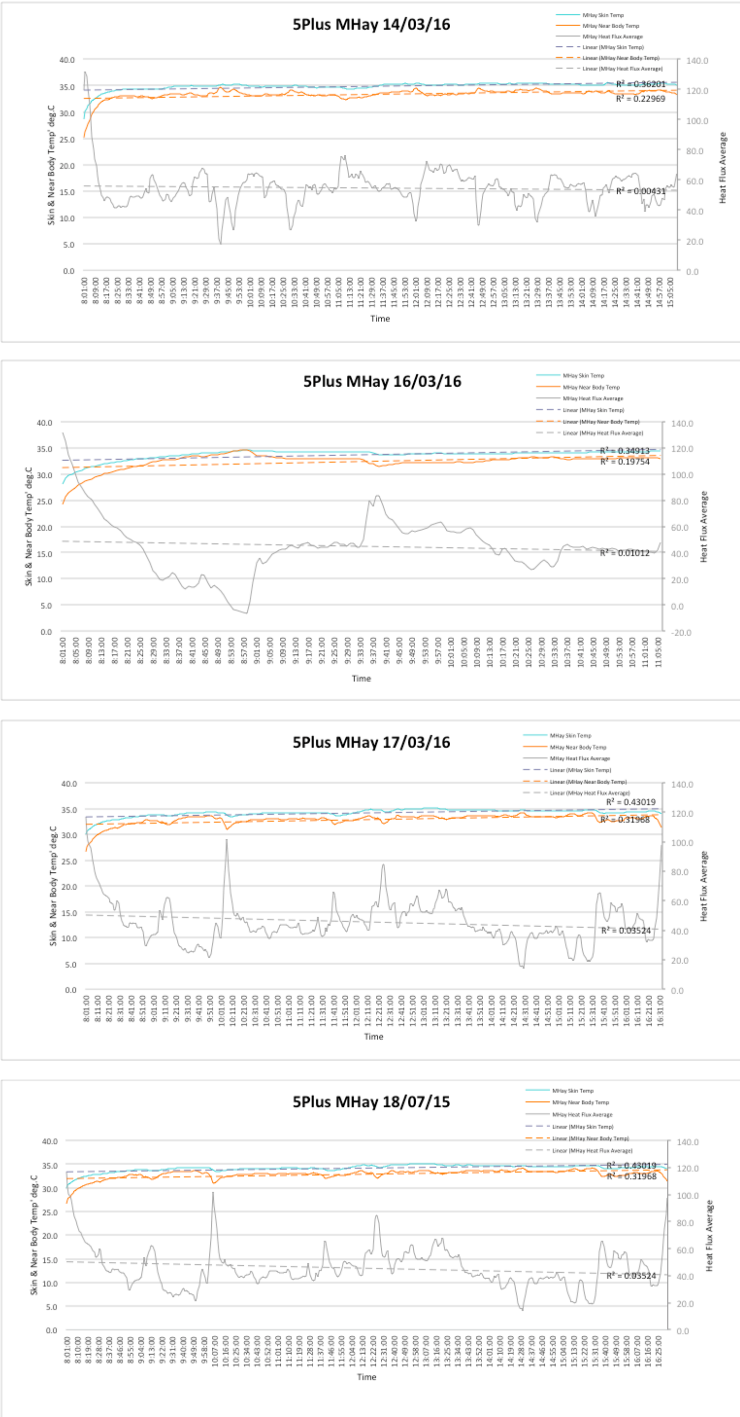
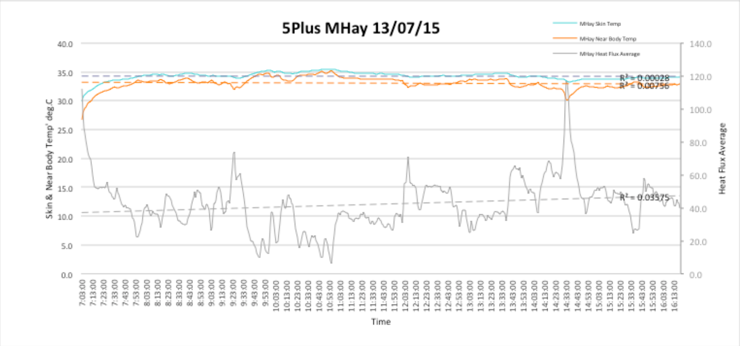
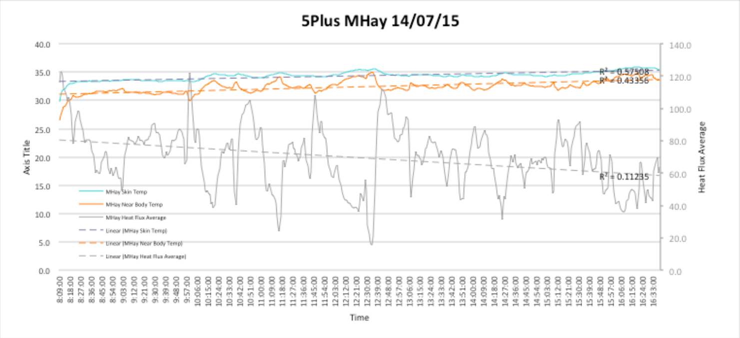
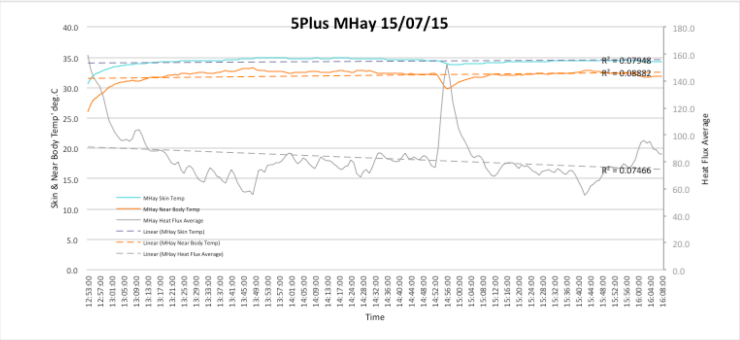


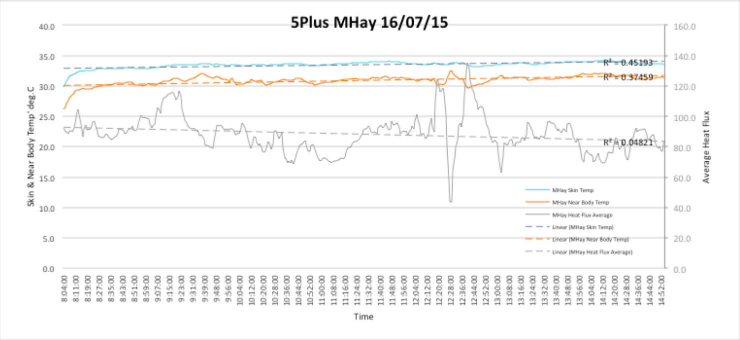
Fig. 84 – MHay Daily Skin & Near Body Temperature and Heat Flux Values March 2016 (Spring)

Note: Volunteer not available on 15/03/16.









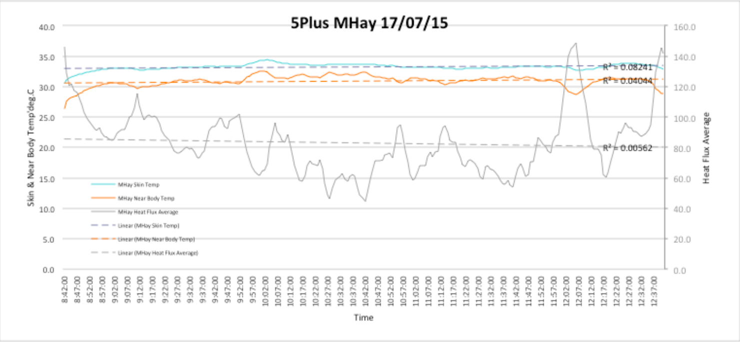


Fig. 85 – MHay Daily Skin & Near Body Temperature and Heat Flux Values July 2015 (Summer)

Fig. 86 – MHay Daily Skin & Near Body Temperature and Heat Flux Values November 2015 (Autumn)

Note: Volunteer not available between 19-20/11/15 inclusive.

Fig. 87 – MHayDaily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

It is again noted that the Skin and Near Body temperature rise continually throughout the day as seen within volunteer (CH) and within normal expected physical body temperature expectations. Heat flux average trends consistently level at varying degrees of R^2. A sharp reduction or increase skin or near body temperature drives an opposite response from heat flux average value which is to be expected as a significant exchange in temperature is experienced. This is consistent with volunteer (CH)

Fig's. 88-91 represents Galvanic Skin Response (GSR) across the seasonal equivalent periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead.

The overall weekly trend for volunteer (MHay) during ***spring,*** indicates a consistent downward trend Mon-Fri, and is someone who appears to be a consistently lease stressful individual over the daily measured period with very view time related stress events.

The overall weekly trend for volunteer (MHay) during ***summer,*** indicates again a downward trend with similar daily profiles. Again the trend for the Summer is a slight reduction in GSR values Mon-Fri but not as progressive as indicated within the spring period. MHay is someone who appears to be a consistently lease stressful individual over the daily measured period with very view time related stress events.

The overall weekly trend for volunteer (MHay) during ***autumn,*** indicates a weekly downward trend in GSR measured values with no significant events recorded. The consistently daily steady state levels are again noted, suggesting MHay is a able to manage his stress, or perhaps the work task is more easily performed. These are psychological aspects of the workplace to which this research is not focusing.

The overall weekly trend for volunteer (MHay) during ***winter,*** indicates an overall weekly continuing downward trend in GSR level, however we not increase in daily values in the afternoon. Upon investigation with the volunteer the volunteer had various project deadlines to address each day in the run up to Xmas. Interestingly the overall weekly GSR remained downwards.

Fig. 88 – GSR Daily and Weekly Measured Values March 2016 (Spring)

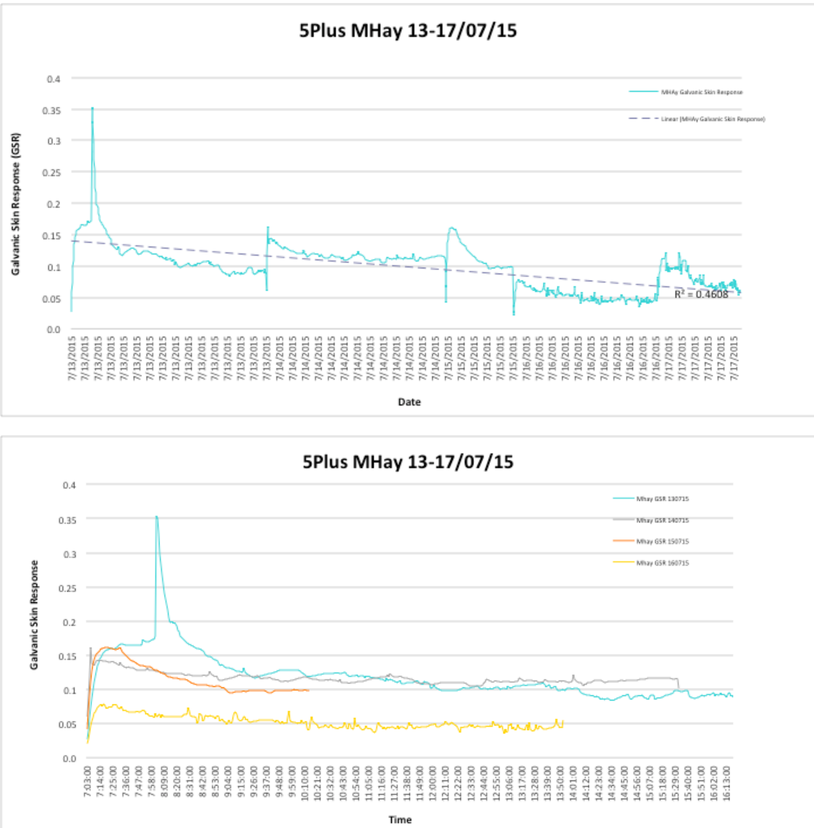


Fig. 89 – GSR Daily and Weekly Measured Values July 2015 (Summer)

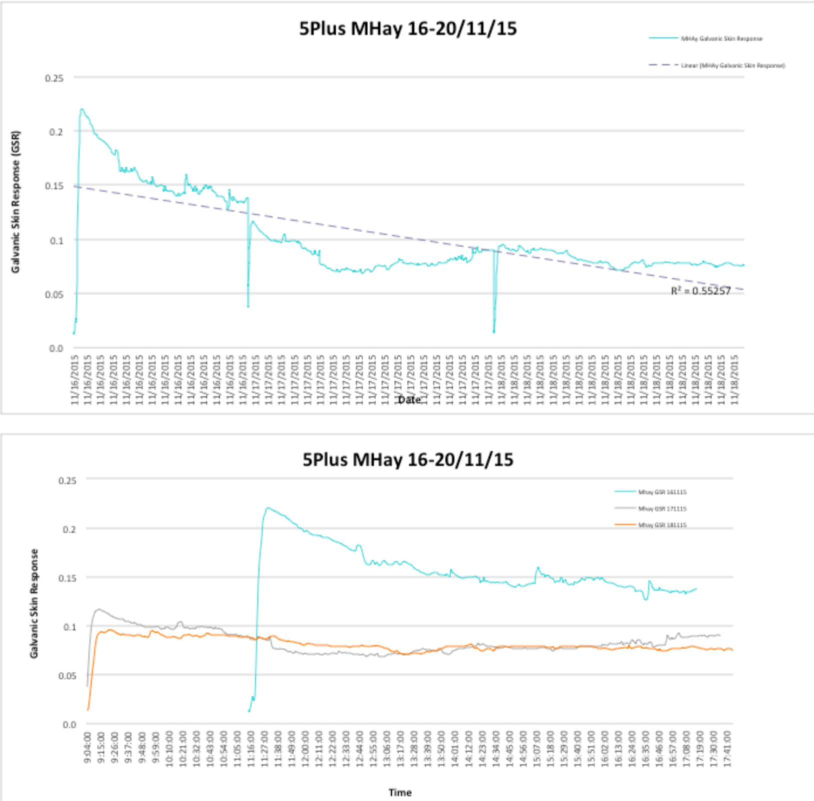


Fig. 90 – GSR Daily and Weekly Measured Values November 2015 (Autumn)

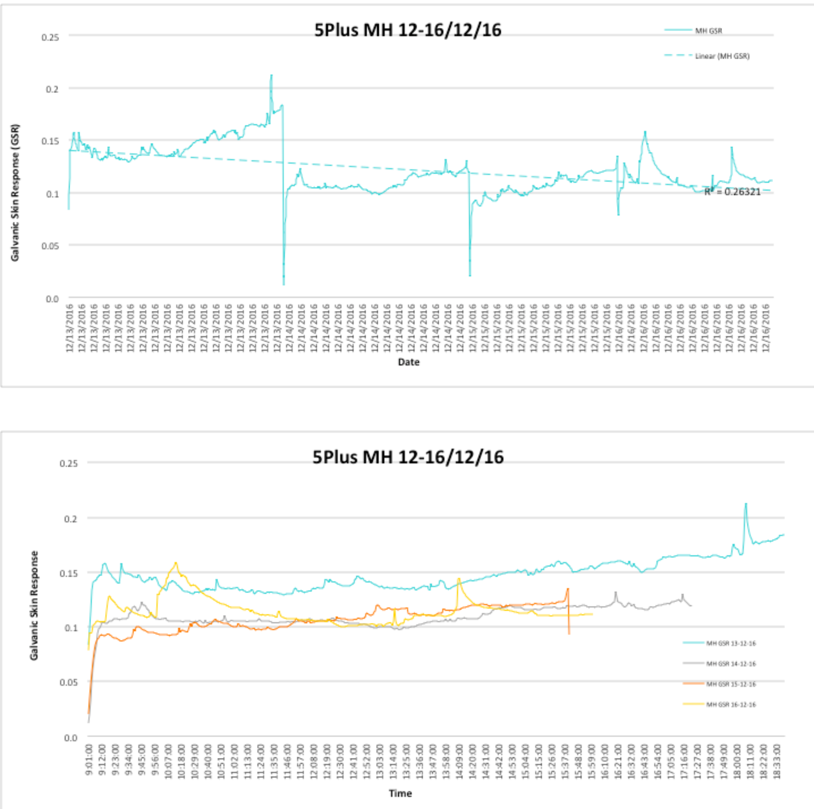


Fig. 91 – GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.3 5+ Architects Volunteer 1 (MHar)

Table 49 indicates the measured data obtained from volunteer (MHar). A non-smoking male of weigh 69.9kg height 182.9cm and BMI of 20.9. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent. Volunteer (MHar) was a consistent and excellent participant with a total armband on body time of 141hrs 33mins (88%) from an expected research time of 160 hrs (8hrs/day x5days/wk x4 seasonal periods). The volunteer missed 4-days out of the office 14/03/16; 16/07/15; 17/11/16 and 20/11/15. The data is considered sufficient for analysis.

The average skin temperature noted within Table 49 across spring, summer, autumn and winter would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. The Weekly (Seasonal) Average Skin Temperature of 32.44 deg.C applied to each seasonal weekly average value indicates a -0.21% decrease during Spring; -0.74% decrease during Summer; 0.29% increase during Autumn; and 0.44% increase during Winter. Across all x4 seasons Maximum values range 1.03% summer to 3.59% during winter with Minimum values ranging between -6.98% during winter to 3.68% during summer.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 29.35 deg.C applied to each seasonal weekly average value indicates a 1.16% increase during Spring; -0.87% decrease during Summer; 0.83% increase during Autumn; and -0.73% decrease during Winter. Across all x4 seasons Maximum figures range 9.08% during spring to 0.57% during winter with Minimum figures ranging between -13.12% autumn to 3.67% during summer.

Heat flux average values although relatively consistent overall between the seasons the graphical representation would propose this physiological measurement is not sufficiently accurate to use within any potential feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 110.40 W/m^2 applied to each seasonal weekly average value indicates a -13.68% decrease during Spring; -1.32% decrease during Summer; 1.27% increase during Autumn; and 12.05% increase during Winter. Across all x4 seasons Maximum figures range 19.41% spring to -5.59% during summer with Minimum figures ranging between -44.90% spring to -7.53% during winter.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (µS) of 1.07E-01 applied to each seasonal weekly average value indicates a 6.90% increase during Spring; -5.40% decrease during Summer; -24.58% decrease during Autumn; and 13.56% increase during Winter. Across all x4 seasons Maximum figures range 166.44% summer to 14.88% during autumn with Minimum figures ranging between -4.99% during winter to -87.97% during autumn.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 7.23 (KJ) applied to each seasonal weekly average value indicates a -39.38% decrease during Spring; 10.25% increase during Summer; 19.63% increase during Autumn; and 11.53% increase during Winter. Across all x4 season's Maximum figures range 57.47% autumn to 31.89% spring with Minimum values ranging between -99.38% spring to -4.89% during autumn/winter. The Weekly (Seasonal) Average Metabolic Equivalent value 1.72 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a 3.28% increase during Spring; -4.55% decrease during Summer; 3.31% increase during Autumn; and -0.97% decrease during winter. Across all x4 season's Maximum figures range 25.08% autumn to 8.67% summer with Minimum figures ranging between -5.29% spring to -6.57% during autumn/winter. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteer Agent - MHar

5 Plus Architects - Manchester - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)				
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	14/03/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tues	15/03/16		8:44	33.46	29.70	29.70	0.12	0.35	31.42	32.59	24.13	0.52	0.72	72.66	197.33	45.59	269.20	16.41
Wed	16/03/16		8:55	31.64	32.32	29.44	0.11	0.33	28.75	30.13	25.34	0.22	0.47	102.61	142.34	68.98	64.21	8.01
Thurs	17/03/16	MHar	9:11	32.65	33.32	31.25	0.22	0.47	29.82	31.14	25.65	0.68	0.83	101.20	211.09	68.71	414.18	20.35
Fri	18/03/16		8:23	31.75	33.15	31.05	0.19	0.44	28.80	29.63	25.34	0.10	0.31	104.72	207.98	84.59	195.34	13.98
Week 1	**Spring**		**35:13**	**32.37**	**33.32**	**29.44**	**0.00**	**0.06**	**29.70**	**32.59**	**24.13**	**0.05**	**0.20**	**95.30**	**211.09**	**45.59**	**16,004.06**	**4.47**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	13/07/15		10:20	31.90	31.90	31.90	31.90	31.90	28.97	28.97	28.97	28.97	28.97	104.44	131.64	59.62	319.48	17.87
Tues	14/07/15		9:53	31.43	31.43	31.43	31.43	31.43	28.19	28.19	28.19	28.19	28.19	114.52	145.57	81.05	186.58	13.66
Wed	15/07/15		10:05	33.07	33.07	33.07	33.07	33.07	30.24	30.24	30.24	30.24	30.24	101.39	166.90	80.43	124.47	11.16
Thurs	16/07/15	MHar	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fri	17/07/15		4:21	32.10	32.10	32.10	32.10	32.10	28.99	28.99	28.99	28.99	28.99	110.91	162.70	96.19	159.92	12.65
Week 2	**Summer**		**39:28**	**32.20**	**33.07**	**31.43**	**0.36**	**0.60**	**29.10**	**30.24**	**28.19**	**0.54**	**0.73**	**108.94**	**166.90**	**59.62**	**5,435.97**	**2.50**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	16/11/15		8:38	32.51	33.28	28.55	0.23	0.48	29.35	30.32	23.63	0.48	0.69	112.79	181.89	99.54	129.70	11.39
Tues	17/11/15		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wed	18/11/15		7:52	32.28	33.12	29.76	0.16	0.40	29.48	30.88	24.20	0.65	0.81	120.20	192.63	102.60	86.25	9.29
Thurs	19/11/15	MHar	9:25	32.82	33.80	30.15	0.20	0.44	29.96	31.25	24.77	0.39	0.62	102.42	187.37	63.23	428.82	20.71
Fri	20/11/15		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 3	**Autumn**		**25:55**	**32.54**	**33.8**	**28.55**	**0.00**	**0.03**	**29.60**	**31.25**	**23.63**	**0.01**	**0.08**	**111.80**	**192.63**	**63.23**	**23,189.19**	**4.96**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	12/12/16		7:29	33.17	33.80	29.96	0.21	0.46	30.05	30.05	30.05	30.05	30.05	114.56	158.70	89.90	87.28	9.34
Tues	13/12/16		9:12	33.13	33.91	29.96	0.36	0.60	29.48	29.48	29.48	29.48	29.48	130.81	188.78	111.19	230.26	15.17
Wed	14/12/16		8:42	32.17	33.32	29.55	0.22	0.47	28.62	28.62	28.62	28.62	28.62	126.63	184.99	102.95	160.74	12.68
Thurs	15/12/16	MHar	8:52	32.81	33.10	28.93	0.10	0.32	29.45	29.45	29.45	29.45	29.45	120.34	192.25	76.52	131.81	11.48
Fri	16/12/16		6:42	31.66	32.41	28.20	0.18	0.42	28.10	28.10	28.10	28.10	28.10	126.16	176.41	92.93	205.75	14.34
Week 4	**Winter**		**40:57**	**32.59**	**33.91**	**28.20**	**0.01**	**0.09**	**29.14**	**30.05**	**28.10**	**0.48**	**0.69**	**123.70**	**192.3**	**76.52**	**2,612.52**	**2.08**
Weekly (Seasonal) Average Summary (x4 wks)			**5 Plus (MHar)**	**32.44**	**32.73**	**30.31**			**29.35**	**29.88**	**27.20**			**110.40**	**176.79**	**82.75**		

Day	Date	Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	14/03/16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tues	15/03/16	2.15E-01	2.15E-01	2.15E-01	2.15E-01	2.15E-01	7.58	17.49	5.65	2.57	1.60	1.56	3.59	1.16	0.11	0.33	1,511
Wed	16/03/16	8.81E-02	8.81E-02	8.81E-02	8.81E-02	8.81E-02	8.41	31.50	5.43	8.76	2.96	1.73	6.47	1.11	0.37	0.61	3,020
Thurs	17/03/16	8.43E-02	8.43E-02	8.43E-02	8.43E-02	8.43E-02	1.46	1.46	1.46	0.00	0.00	2.03	7.68	1.05	1.34	1.16	7,208
Fri	18/03/16	7.17E-02	7.17E-02	7.17E-02	7.17E-02	7.17E-02	0.07	0.17	0.03	0.00	0.03	1.79	7.01	1.19	0.74	0.86	3,186
Week 1	**Spring**	**1.15E-01**	**2.15E-01**	**7.17E-02**	**3.41E-03**	**5.84E-02**	**4.38**	**31.50**	**0.03**	**12.82**	**1.23**	**1.77**	**7.68**	**1.05**	**0.21**	**0.31**	**3,731**
Analysis 2		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	13/07/15	1.11E-01	4.11E-01	1.25E-02	1.93E-03	4.39E-02	7.87	27.35	5.08	5.25	2.29	1.62	5.62	1.04	0.22	0.47	1,262
Tues	14/07/15	1.07E-01	1.97E-01	9.52E-03	3.63E-04	1.90E-02	7.84	27.94	5.21	4.99	2.23	1.63	6.71	1.07	0.22	0.47	1,219
Wed	15/07/15	9.07E-02	2.01E-01	6.81E-02	5.16E-04	2.27E-02	7.81	32.68	5.75	4.19	2.05	1.60	6.71	1.18	0.18	0.42	1,466
Thurs	16/07/15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fri	17/07/15	9.78E-02	1.80E-01	6.74E-02	1.07E-03	3.27E-02	8.35	23.37	6.11	7.69	2.77	1.72	4.80	1.25	0.32	0.57	1,412
Week 2	**Summer**	**1.02E-01**	**4.11E-01**	**9.52E-03**	**3.76E-07**	**9.66E-03**	**7.97**	**32.68**	**5.08**	**1.71**	**0.27**	**1.64**	**6.71**	**1.04**	**0.00**	**0.05**	**1,340**
Analysis 3		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	16/11/15	9.28E-02	1.77E-01	1.03E-02	5.97E-04	2.44E-02	8.20	31.88	5.07	12.82	3.58	1.68	6.54	1.04	0.54	0.73	3,298
Tues	17/11/15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wed	18/11/15	6.95E-02	1.07E-01	1.54E-02	1.45E-04	1.21E-02	9.39	35.83	5.07	29.69	5.45	1.93	7.36	1.04	1.25	1.12	3,279
Thurs	19/11/15	8.08E-02	1.27E-01	1.47E-02	1.43E-04	1.20E-02	8.36	37.61	5.55	20.13	4.49	1.72	7.72	1.14	0.85	0.92	3,725
Fri	20/11/15	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 3	**Autumn**	**8.10E-02**	**1.77E-01**	**1.03E-02**	**4.57E-08**	**5.86E-03**	**8.65**	**37.61**	**5.07**	**47.75**	**0.76**	**1.78**	**7.72**	**1.04**	**0.08**	**0.16**	**3,434**
Analysis 4		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	12/12/16	1.06E-01	1.06E-01	1.06E-01	1.06E-01	1.06E-01	7.52	11.31	5.48	1.04	1.02	1.54	2.32	1.12	0.04	0.21	1,233
Tues	13/12/16	8.05E-02	8.05E-02	8.05E-02	8.05E-02	8.05E-02	8.84	32.32	5.07	20.13	4.49	1.81	6.63	1.04	0.85	0.92	2,481
Wed	14/12/16	2.37E-01	2.37E-01	2.37E-01	2.37E-01	2.37E-01	7.99	26.28	5.23	6.08	2.47	1.64	5.39	1.07	0.26	0.51	1,210
Thurs	15/12/16	7.53E-02	7.53E-02	7.53E-02	7.53E-02	7.53E-02	8.45	33.66	5.62	18.00	4.24	1.73	6.91	1.15	0.76	0.87	3,250
Fri	16/12/16	1.12E-01	1.12E-01	1.12E-01	1.12E-01	1.12E-01	7.52	11.31	5.48	1.04	1.02	1.78	7.31	1.13	0.81	0.90	2,392
Week 4	**Winter**	**1.22E-01**	**2.37E-01**	**7.53E-02**	**3.51E-03**	**5.92E-02**	**8.06**	**33.66**	**5.07**	**68.00**	**1.50**	**1.70**	**7.31**	**1.04**	**0.11**	**0.28**	**2,113**
Weekly (Seasonal) Average Summary (x4 wks)	**5 Plus (MHar)**	**1.07E-01**	**1.54E-01**	**7.92E-02**			**7.23**	**23.89**	**4.83**			**1.72**	**6.17**	**1.11**			**2,655**

Seasonal Weekly % Average difference																				
Week 1	*Spring*	**5 Plus (MHar)**	-0.21%	1.80%	-2.87%	1.16%	9.08%	-11.26%	-13.68%	19.41%	-44.90%	6.90%	39.52%	-9.53%	-39.38%	31.89%	-99.38%	3.28%	24.44%	-5.29%	40.56%
Week 2	*Summer*		-0.74%	1.03%	3.68%	-0.87%	1.22%	3.67%	-1.32%	-5.59%	-27.95%	-5.40%	166.44%	-87.97%	10.25%	36.82%	5.16%	-4.55%	8.67%	-6.33%	-49.53%
Week 3	*Autumn*		0.29%	3.25%	-5.80%	0.83%	4.59%	-13.12%	1.27%	8.96%	-23.59%	-24.58%	14.88%	-87.05%	19.63%	57.47%	4.89%	3.31%	25.08%	-6.57%	29.36%
Week 4	*Winter*		0.44%	3.59%	-6.98%	-0.73%	0.57%	3.34%	12.05%	8.75%	-7.53%	13.56%	53.59%	-4.99%	11.53%	40.93%	4.89%	-0.97%	18.46%	-6.57%	-20.39%

Abbreviations

Avge *Average mean value of all arguments*
Max *Maximum value within data set*
Min *Minimum value within data set*
Var *Variance from the average mean across the data set*
SD *Standard Deviation from the average mean value across the data set*
N/A *Volunteer Not Available*

Table 49 - Sensewear Armband Measured Values – Volunteer (MHar)

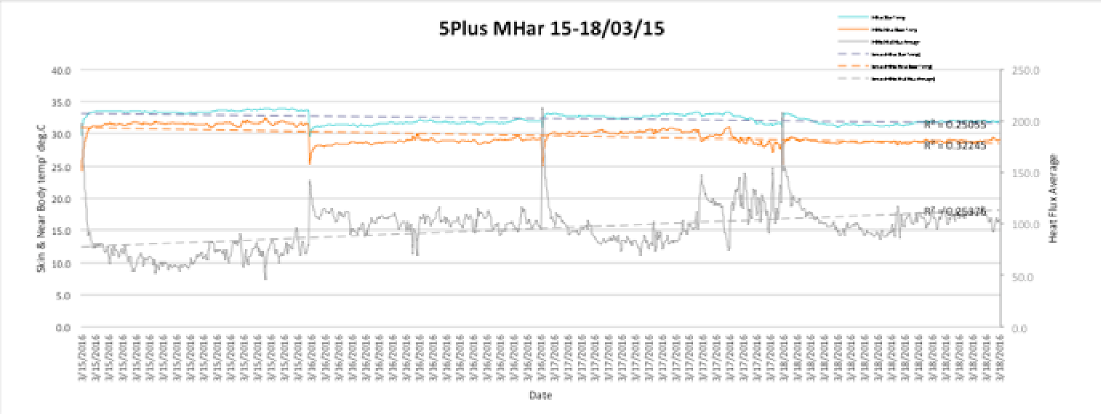


Fig . 92 – MHar Seasonal Skin & Near Body Temperature and Heat Flux – March 2015 (Spring)

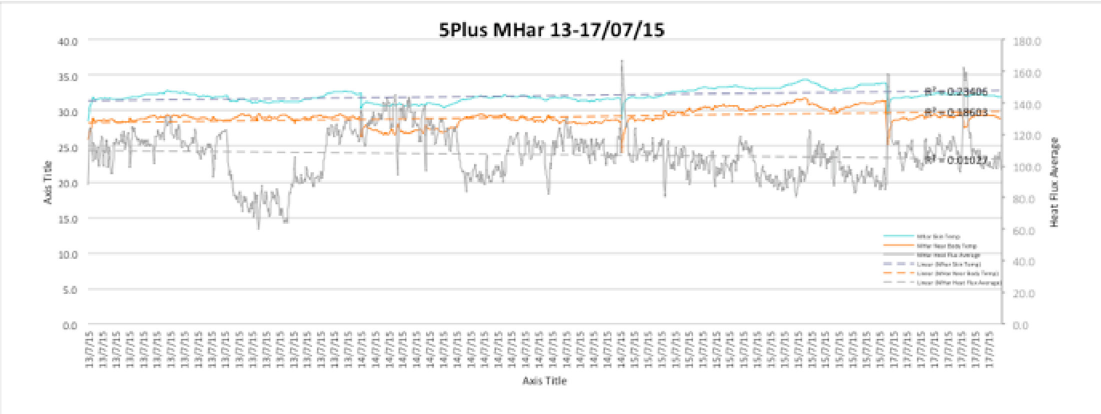


Fig. 93 – MHar Seasonal Skin & Near Body Temperature and Heat Flux – July 2015 (Summer)

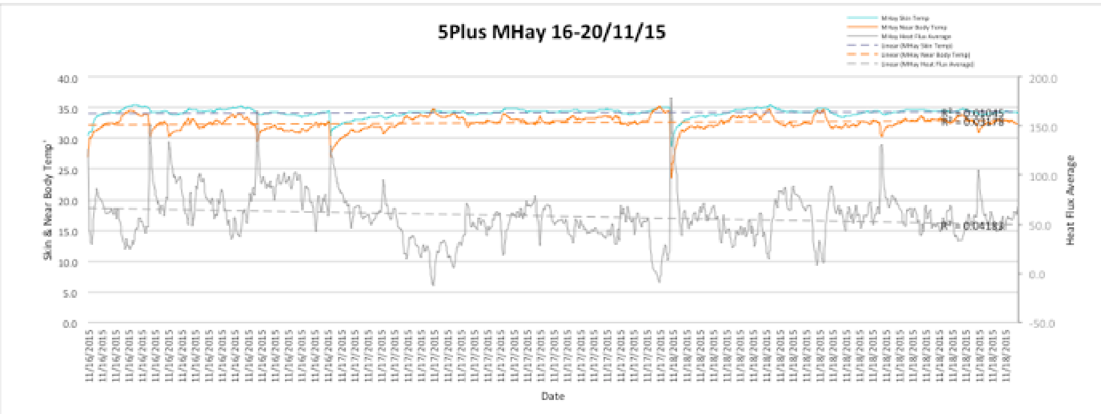


Fig. 94 – MHar Seasonal Skin & Near Body Temperature and Heat Flux – November 2015 (Autumn)

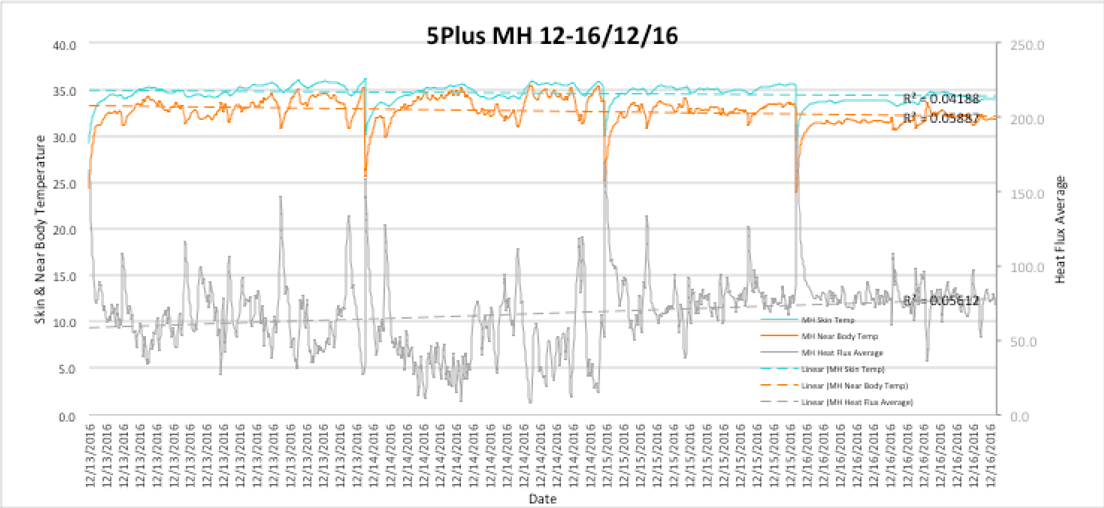


Fig. 95 – MHar Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Fig's. 92-95 represents the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 50. As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier. Similar results were found with volunteer (CH & MHay)

Heat Flux average is again a more variable set of values with greater R^2 values and upward inclination of the trend line over spring and winter. The spring and winter periods indicate a increasing trend, however, summer and autumn indicate a relative level but decreasing trend over the weekly period. The expectation that winter heat flux would be lower and a reducing trend is not supported from the measured values.

The following Fig's. 97-99 represents a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

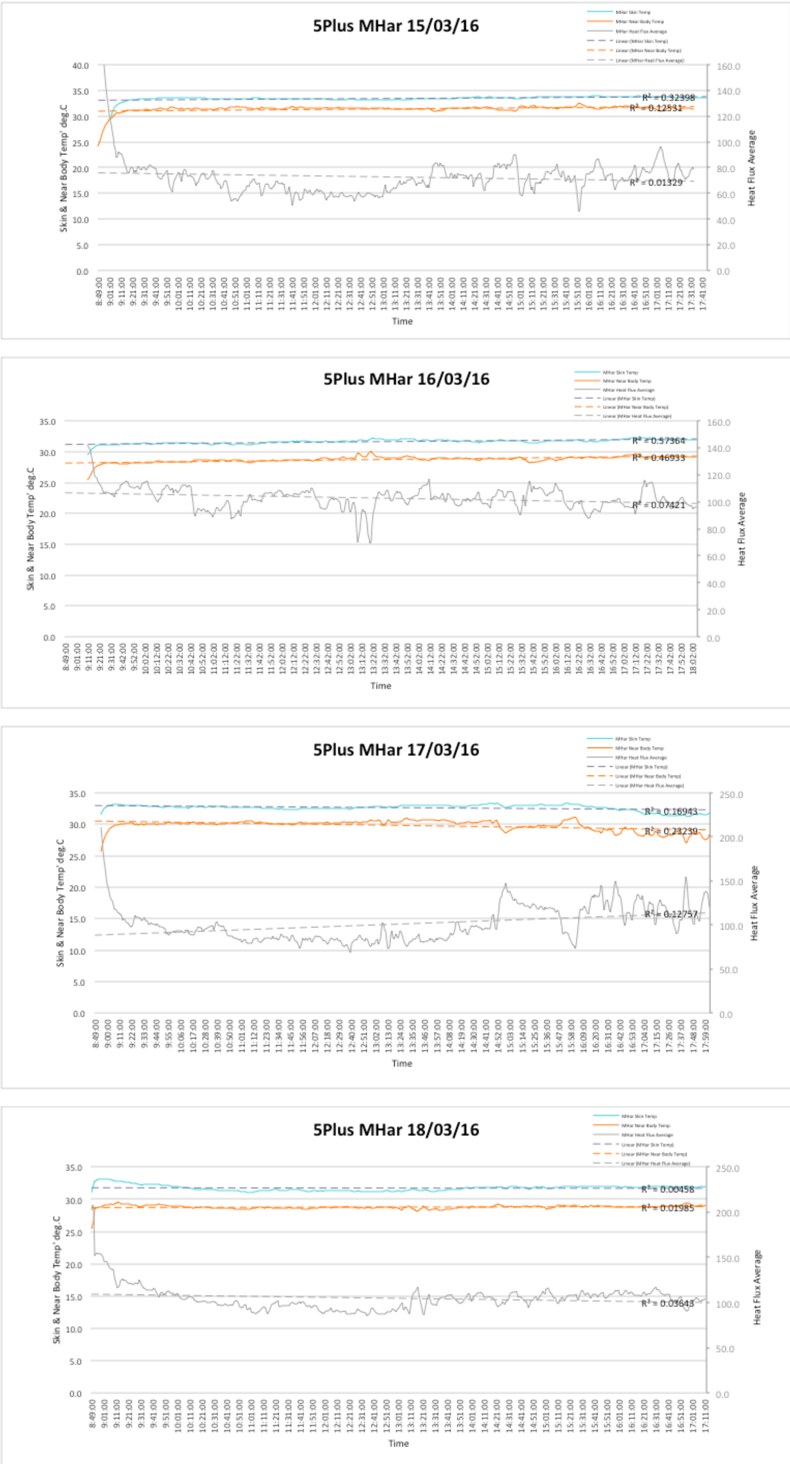
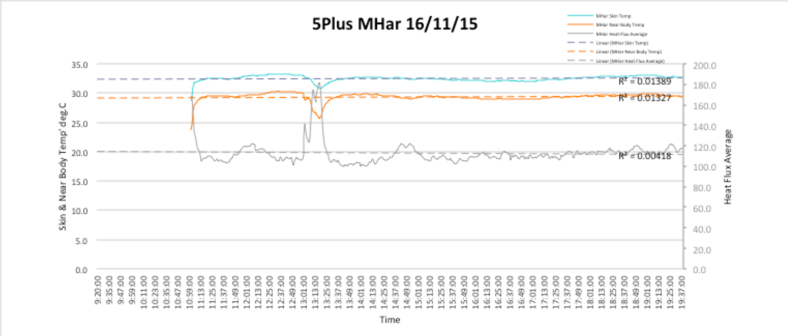
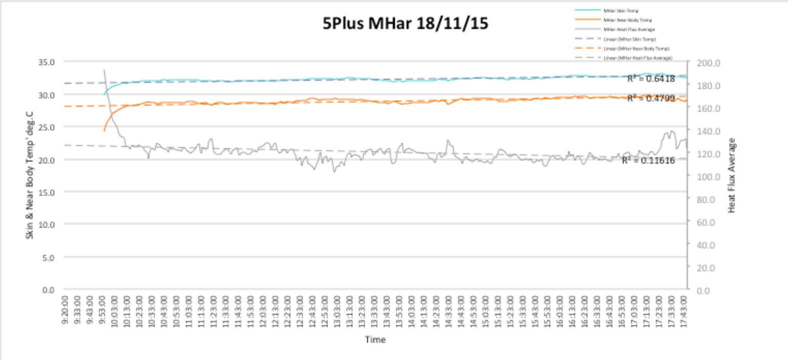


Fig. 96 – MHar Daily Skin & Near Body Temperature and Heat Flux Values March 2016 (Spring)

Fig. 97 – MHar Daily Skin & Near Body Temperature and Heat Flux Values July 2015 (Summer)





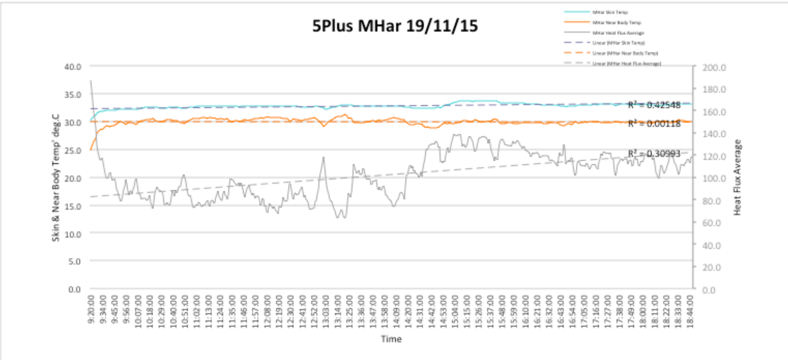


Fig. 98 – MHar Daily Skin & Near Body Temperature and Heat Flux Values November 2015 (Autumn)

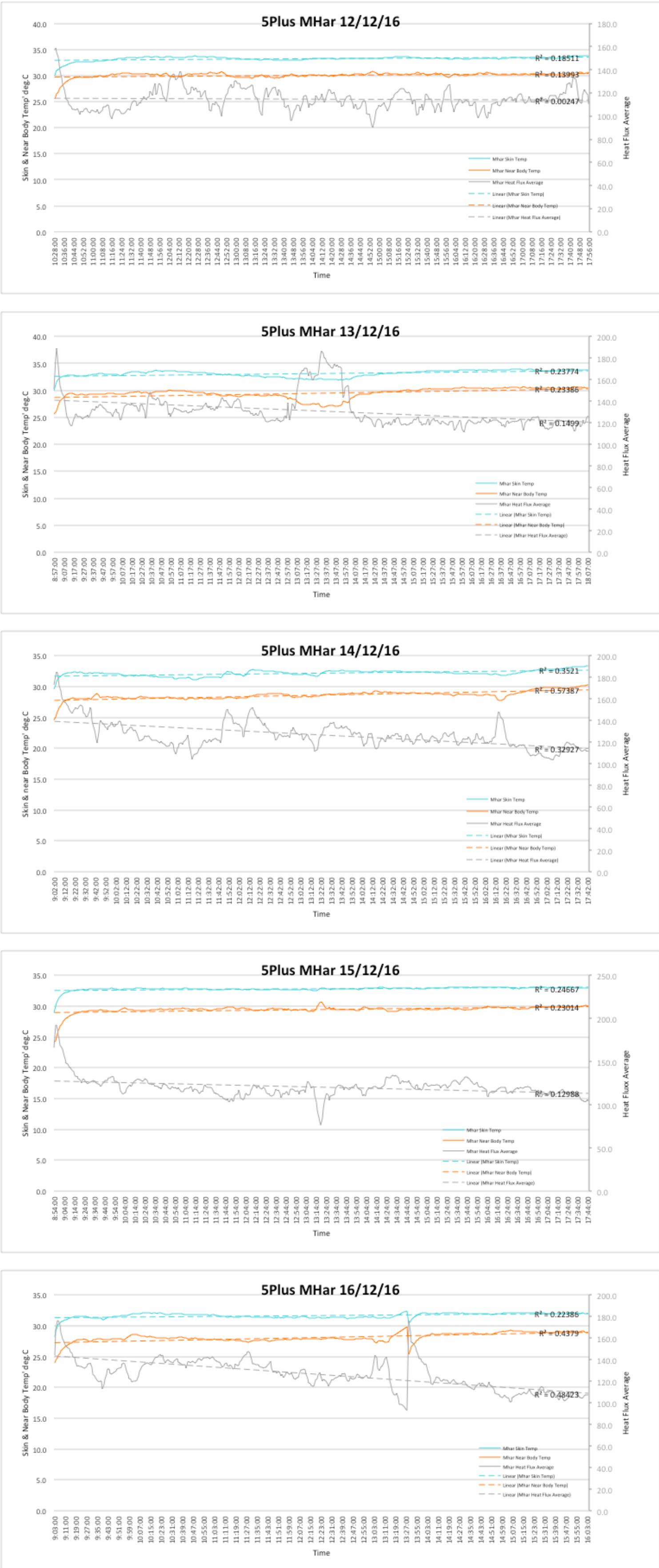


Fig. 99 – MHar Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

Within Fig's. 97-99 the Skin and Near Body temperature rises continually throughout the day as seen within other volunteers (CH & MHay) and within normal expected physical body temperature expectations.

Fig's. 100-103 represents Galvanic Skin Response (GSR) and indicate the equivalent seasonal periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead.

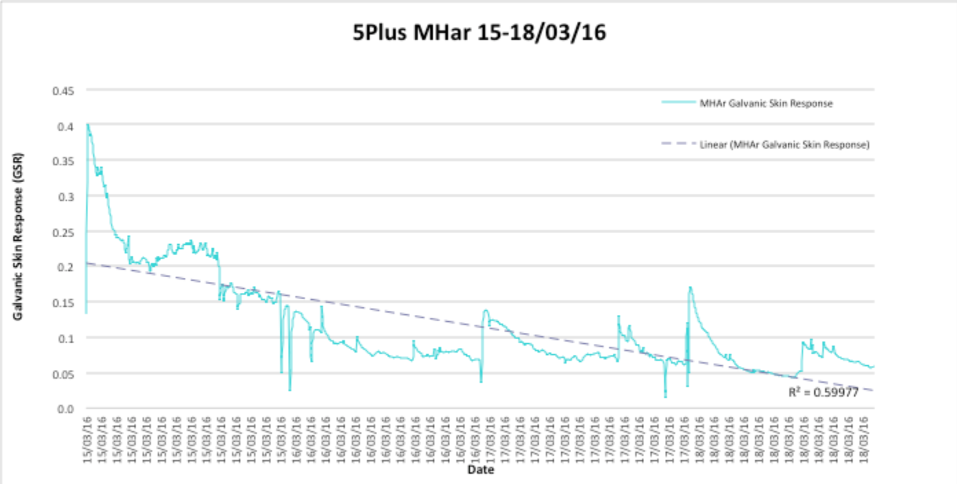
The overall weekly trend for volunteer (MHar) during ***spring,*** indicates a consistent downward trend Mon-Fri. The sharp increases in GSR are indicative of daily issues experienced either meetings or conflict situations, however, MHar appears to be a consistently lease stressful individual over the daily measured period similar to MHay.

The overall weekly trend for volunteer (MHar) during ***summer,*** are significantly different in respect of decreasing trend and profile with only a slight downward trend Mon-Fri. The morning start data values need to be cleansed once down loaded, hence the profile difference. This was subsequently confirmed to be the volunteer wearing the armband to loose during the early morning period. The early morning periods are represented by the x4 peaks detailed as the dates change on the upper graph, the volunteer indicates a set of decreasing and consistent trends for each day Wed-Fri.The fitting of the armband now resolved with the volunteer, the volunteer was unavailable on the 17 & 20th Nov 2015 however the graphical output remains consistent with expectations from other volunteers. The volunteer displays again a more significant reducing trend Mon-Thurs with the Wednesday <u>not</u> indicating a higher value despite the previous day being out of the office. This may suggest the weekend (relaxing) transitions to higher GSR values as seen on a Monday post the weekend. Days out of the office are being considered as work periods. The Thurs peak just after lunch is a consequence of an important client meeting, which once completed GSR values return to lower more typical values for the volunteer.

The overall weekly trend for volunteer (MHar) during ***Autumn,*** indicates a consistent GSR downward trend Mon-Fri and a return to more traditional GSR daily profiling.

The overall weekly trend for volunteer (MHar) during ***winter,*** again saw data issues at the start of the day and these needed to be cleansed due to inappropriate wearing of the armband. The remaining days the volunteer experienced much lower GSR values consistent with other daily periods post other events. The overall GSR trend was a slight decrease Mon – Fri however this trend was impacted significantly due to the events and values experienced during Wednesday morning.

A reducing trend pattern is forming at 5Plus Architects with the volunteers displaying similar GSR decreasing trends Mon-Fr. Tuesdays being the 1st day back to work post the weekend displayed high GSR values but with subsequent days indicating similar profiles and decreasing values. Where sharp increases are noted these remain to be work related or time dependant.



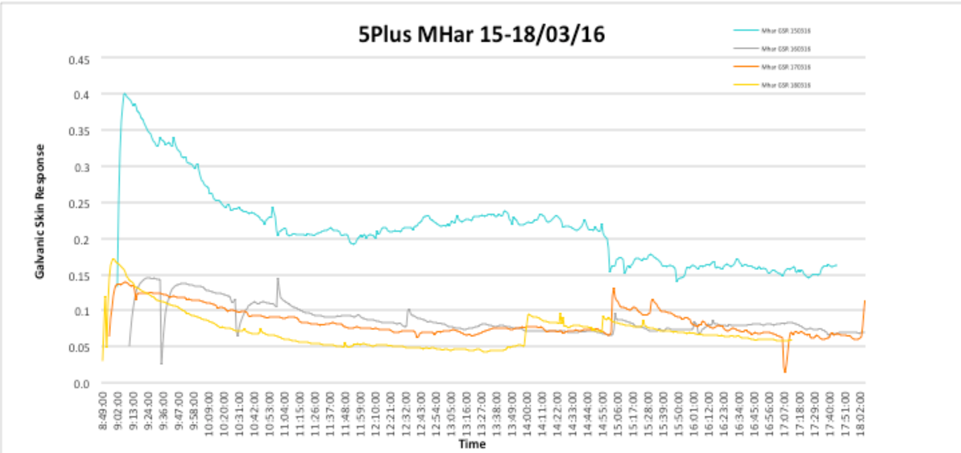


Fig. 100 – MHar GSR Daily and Weekly Measured Values March 2016 (Spring)

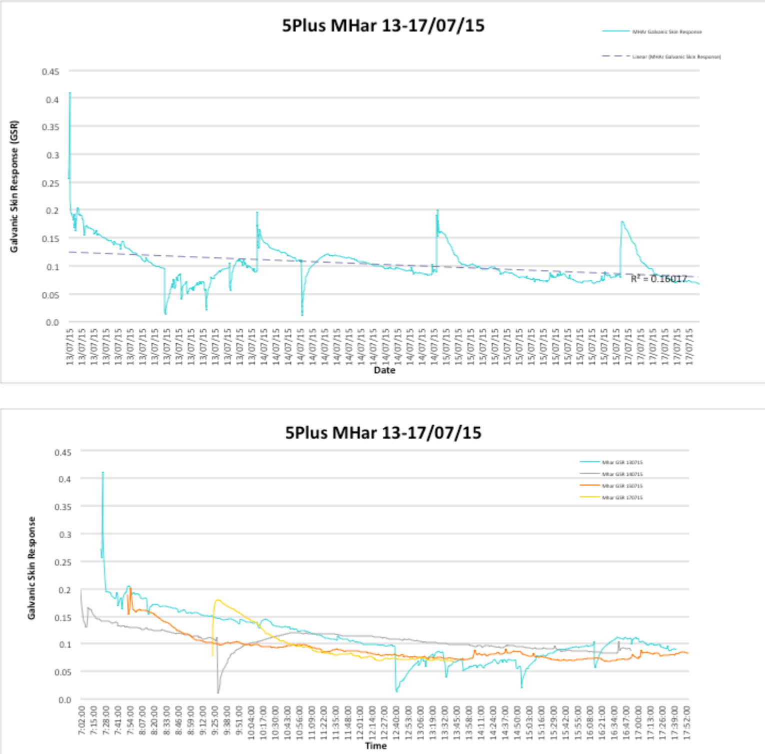


Fig. 101 – MHar GSR Daily and Weekly Measured Values July 2015 (Summer)

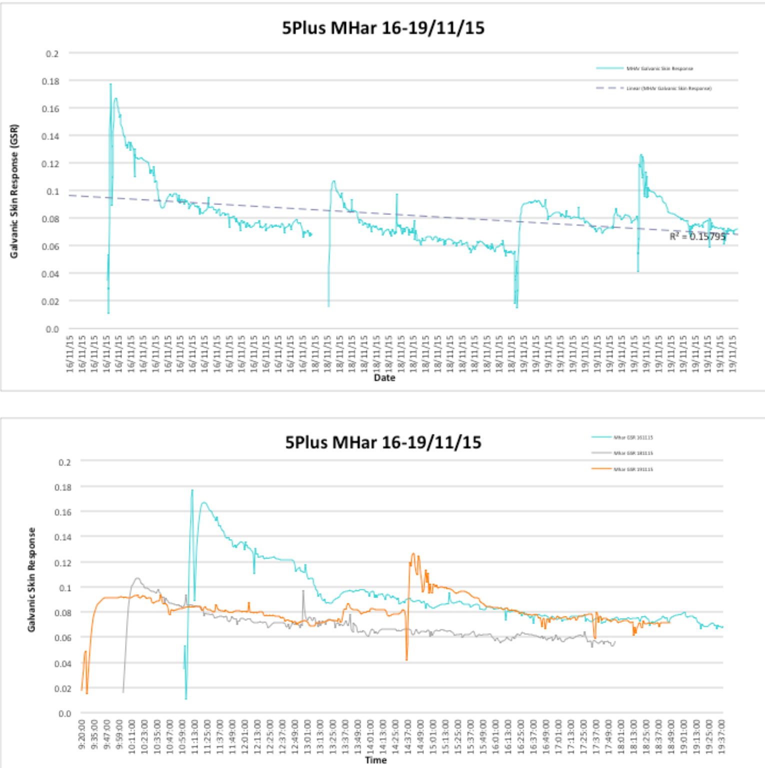


Fig. 102 – MHar GSR Daily and Weekly Measured Values November 2015 (Autumn)

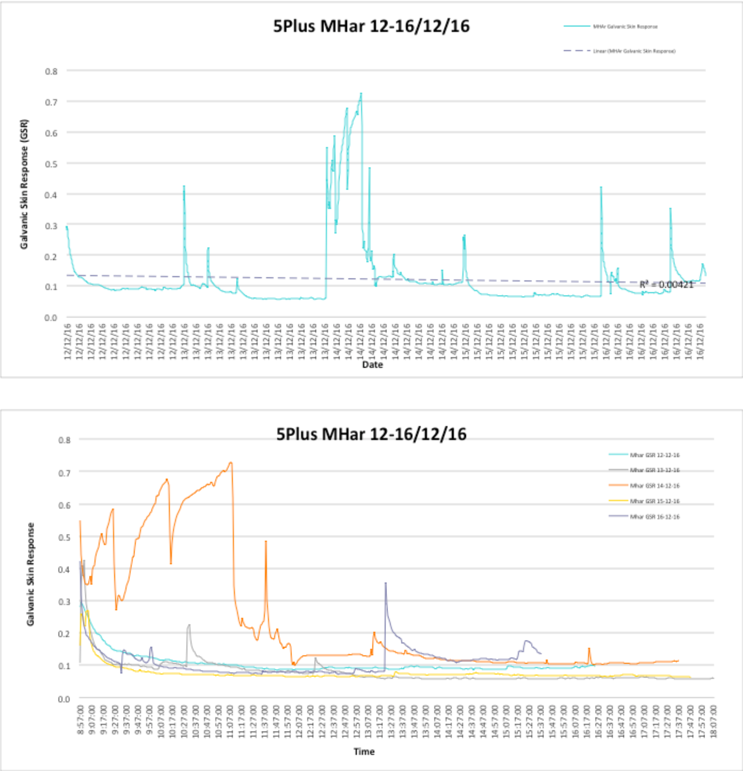


Fig. 103 – MHar GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.4 5+ Architects Volunteer 1 (RB)

Table 50 indicates the measured data obtained from volunteer (RB). A non-smoking male of weight 90.7kg height 182.9cm and BMI of 27.1. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent. Volunteer (RB) was a consistent and excellent participant with a total armband on body time of 142hrs 27mins (88%) from an expected research time of 160 hrs (8hrs/day x5days/wk x4 seasonal periods). The volunteer missed 2-days out of the office 16/03/16 and 16/07/15. The data is considered sufficient for analysis.

The average skin temperature noted within Table 50 across spring, summer, autumn and winter would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. fThe Weekly (Seasonal) Average Skin Temperature of 33.72 deg.C applied to each seasonal weekly average value indicates a 0.92% increase during

Spring; -2.69% decrease during Summer; 0.38% increase during Autumn; and 1.04% increase during Winter. Across all x4 seasons Maximum values range 2.66% spring to -1.45% during summer with Minimum values ranging between -6.73% during winter to -2.77% during autumn.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 30.36 deg.C applied to each seasonal weekly average value indicates a 1.25% increase during Spring; -1.55% decrease during Summer; -0.02% decrease during Autumn; and 0.26% increase during Winter. Across all x4 seasons Maximum figures range 4.70% during spring to 1.47% during autumn with Minimum figures ranging between -9.84% spring to -1.72% during spring.

Heat flux average values although relatively consistent overall between the seasons the graphical representation would propose that this physiological measurement is not sufficiently accurate to use within any potential feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally, however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 120.60 W/m^2 applied to each seasonal weekly average value indicates a -1.70% decrease during Spring; -12.84% decrease during Summer; 4.49% increase during Autumn; and 8.69% increase during Winter. Across all x4 seasons Maximum figures range -5.54% spring to 26.3% during winter with Minimum figures ranging between -46.08% during summer to 2.77% increase during winter.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (μS) of 1.49E-01 applied to each seasonal weekly average value indicates a 4.17% increase during Spring; 52.11% increase during Summer; 9.67% increase during Autumn; and -54.70% decrease during Winter. Across all x4 seasons Maximum figures range -9.40% winter to 132.29% during spring with Minimum figures ranging between -86.74% during spring to 31.83% during summer.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal)

Average Energy Expended value 10.38 (KJ) applied to each seasonal weekly average value indicates a -4.56% decrease during Spring; -0.70% decrease during Summer; 3.01% increase during Autumn; and 1.2% increase during Winter. Across all x4 season's Maximum figures range 0.41% during spring to 45.43% during winter with Minimum values ranging between -6.46% during spring/autumn/winter to -2.73% during spring. The Weekly (Seasonal) Average Metabolic Equivalent value 1.62 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -3.54% decrease during Spring; -5.08% decrease during Summer; 4.37% increase during Autumn; and 2.53% increase during winter. Across all x4 season's Maximum figures range 1.71% spring to 47.31% winter with Minimum figures ranging between -5.22% spring/autumn/winter to -7.02% during spring. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteer Agent - RB

5 Plus Architects - Manchester - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)					Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	\	Max	Min	Var	SD	Count
Mon	14/03/16		5:52	34.08	35.03	30.32	0.44	0.66	30.54	31.69	26.84	0.34	0.58	127.97	180.10	97.29	212.75	14.59	2.04E-01	5.16E-01	3.96E-02	6.26E-03	7.91E-02	10.16	33.92	6.00	28.27	5.32	1.59	5.36	0.95	0.56	0.75	2,612
Tues	15/03/16		8:39	33.27	34.61	29.46	0.80	0.89	30.02	31.38	25.73	1.29	1.13	116.83	235.74	86.51	562.15	23.71	7.35E-02	2.12E-01	1.25E-02	4.18E-04	2.04E-02	10.00	29.16	6.00	18.11	4.26	1.58	4.61	0.95	0.45	0.67	3,293
Wed	16/03/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thurs	17/03/16	RB	6:44	34.39	35.03	30.92	0.38	0.61	31.05	32.48	26.53	0.82	0.90	120.84	187.61	85.98	256.90	16.03	2.41E-01	6.69E-01	1.21E-01	8.39E-03	9.16E-02	10.29	32.54	6.39	35.86	5.99	1.63	5.14	1.01	0.90	0.95	3,732
Fri	18/03/16		8:20	34.37	35.54	27.53	1.43	1.20	31.36	33.06	22.49	2.80	1.67	108.53	213.38	83.89	579.30	24.07	1.02E-01	1.30E-01	7.33E-02	2.28E-04	1.51E-02	9.17	30.68	6.10	11.54	3.40	1.45	4.85	0.96	0.29	0.54	2,361
Week 1	**Spring**		**29:35**	**34.03**	**35.54**	**27.53**	**0.18**	**0.23**	**30.74**	**33.06**	**22.49**	**0.85**	**0.40**	**118.54**	**235.74**	**83.89**	**28,488.25**	**4.32**	**1.55E-01**	**6.69E-01**	**1.25E-02**	**1.28E-05**	**3.41E-02**	**9.90**	**33.92**	**6.00**	**86.90**	**0.99**	**1.56**	**5.36**	**0.95**	**0.05**	**0.15**	**3,000**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	13/07/15		8:25	32.99	33.68	29.76	0.27	0.52	30.11	31.56	25.24	0.66	0.81	103.15	181.47	73.87	262.48	16.20	3.71E-01	3.71E-01	3.71E-01	3.71E-01	3.71E-01	10.40	33.11	7.00	22.79	4.77	1.55	4.94	1.04	0.51	0.71	3,380
Tues	14/07/15		7:40	32.99	34.11	27.49	1.22	1.11	30.27	31.82	24.52	1.43	1.20	97.26	145.49	77.28	90.64	9.52	1.43E-01	1.43E-01	1.43E-01	1.43E-01	1.43E-01	9.14	29.91	6.65	11.09	3.33	1.36	4.46	0.99	0.25	0.50	1,826
Wed	15/07/15		10:23	32.66	33.75	28.83	0.81	0.90	29.82	31.66	24.58	1.44	1.20	101.50	174.52	49.64	281.64	16.78	1.24E-01	1.24E-01	1.24E-01	1.24E-01	1.24E-01	10.97	41.20	6.24	31.41	5.60	1.64	6.14	0.93	0.70	0.84	4,868
Thurs	16/07/15	RB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fri	17/07/15		5:48	32.61	33.68	30.36	0.35	0.59	29.35	30.38	27.69	0.31	0.56	116.58	148.49	80.91	121.81	11.04	2.69E-01	2.69E-01	2.69E-01	2.69E-01	2.69E-01	10.71	32.93	6.78	24.81	4.98	1.60	4.91	1.01	0.55	0.74	3,380
Week 2	**Summer**		**32:16**	**32.81**	**34.11**	**27.49**	**0.15**	**0.24**	**29.89**	**31.82**	**24.52**	**0.24**	**0.27**	**105.12**	**181.47**	**49.64**	**7,042.81**	**3.16**	**2.27E-01**	**3.71E-01**	**1.24E-01**	**1.00E-02**	**1.00E-01**	**10.30**	**41.20**	**6.24**	**53.73**	**0.83**	**1.54**	**6.14**	**0.93**	**0.03**	**0.12**	**3,364**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	16/11/15		6:43	34.10	34.91	28.55	0.51	0.72	30.80	31.69	24.09	0.86	0.93	118.87	180.50	93.25	226.72	15.06	1.29E-01	4.44E-01	2.64E-02	2.86E-03	5.35E-02	10.35	34.24	6.30	26.20	5.12	1.64	5.41	1.00	0.65	0.81	3,032
Tues	17/11/15		8:36	33.44	34.18	28.79	0.49	0.70	29.84	30.69	24.62	0.67	0.82	129.55	198.68	115.37	124.32	11.15	1.70E-01	4.33E-01	9.82E-02	3.42E-03	5.85E-02	9.98	30.11	6.00	19.02	4.36	1.58	4.76	0.95	0.48	0.69	2,621
Wed	18/11/15		8:41	33.39	34.43	30.02	0.49	0.70	29.73	30.66	25.46	0.56	0.75	131.99	171.13	105.71	95.39	9.77	9.51E-02	3.25E-01	4.25E-02	2.11E-03	4.60E-02	10.83	36.44	6.84	29.76	5.46	1.71	5.76	1.08	0.74	0.86	3,931
Thurs	19/11/15	RB	8:23	34.28	34.98	28.26	0.53	0.73	30.97	32.04	23.32	1.05	1.03	119.83	188.75	73.47	207.39	14.40	2.57E-01	4.54E-01	8.06E-02	8.39E-03	9.16E-02	10.03	39.99	6.00	16.18	4.02	1.59	6.32	0.95	0.40	0.64	1,963
Fri	20/11/15		7:14	34.03	35.07	29.06	0.74	0.86	30.43	31.75	24.83	1.58	1.26	129.84	218.50	103.21	591.33	24.32	1.66E-01	2.39E-01	1.11E-01	4.04E-04	2.01E-02	12.26	33.56	6.00	39.73	6.30	1.94	5.30	0.95	0.99	1.00	4,608
Week 3	**Autumn**		**39:37**	**33.85**	**35.07**	**28.26**	**0.01**	**0.06**	**30.35**	**32.04**	**23.32**	**0.13**	**0.18**	**126.01**	**218.50**	**73.47**	**31,711.28**	**5.09**	**1.63E-01**	**4.54E-01**	**2.64E-02**	**7.15E-06**	**2.30E-02**	**10.69**	**39.99**	**6.00**	**69.54**	**0.81**	**1.69**	**6.32**	**0.95**	**0.04**	**0.13**	**3,231**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	12/12/16		8:06	34.23	35.07	28.68	0.80	0.90	30.34	31.51	24.72	1.46	1.21	140.76	242.40	105.11	764.05	27.64	8.34E-02	2.29E-01	2.27E-02	9.09E-04	3.02E-02	12.32	49.13	6.69	79.13	8.90	1.95	7.77	1.06	1.98	1.41	4,293
Tues	13/12/16		8:40	33.87	34.73	29.04	0.50	0.71	30.07	31.27	24.95	0.65	0.81	137.22	227.26	110.73	179.47	13.40	6.87E-02	2.61E-01	2.78E-02	5.13E-04	2.27E-02	10.32	31.32	6.00	21.87	4.68	1.63	4.95	0.95	0.55	0.74	2,278
Wed	14/12/16		8:31	34.21	34.73	29.74	0.49	0.70	31.00	32.06	25.95	0.78	0.88	116.06	163.47	94.62	110.96	10.53	6.26E-02	1.46E-01	3.96E-02	2.62E-04	1.62E-02	10.57	30.20	7.15	26.05	5.10	1.67	4.77	1.13	0.65	0.81	3,839
Thurs	15/12/16	RB	8:36	34.04	34.64	29.25	0.62	0.79	30.38	31.25	24.74	0.92	0.96	132.20	194.41	113.48	164.50	12.83	5.30E-02	1.16E-01	3.81E-02	2.21E-04	1.49E-02	9.18	28.52	6.57	14.64	3.83	1.45	4.51	1.04	0.37	0.60	2,858
Fri	16/12/16		7:06	34.00	34.91	27.11	1.29	1.14	30.42	31.38	22.78	1.66	1.29	129.16	202.84	106.81	266.09	16.31	6.97E-02	1.05E-01	5.06E-02	4.83E-05	6.95E-03	10.12	31.09	6.75	19.78	4.45	1.60	4.92	1.07	0.49	0.70	2,714
Week 4	**Winter**		**40:59**	**34.07**	**35.07**	**27.11**	**0.09**	**0.16**	**30.44**	**32.06**	**22.78**	**0.16**	**0.19**	**131.08**	**242.4**	**94.62**	**57,014.16**	**6.04**	**6.75E-02**	**2.61E-01**	**2.27E-02**	**8.93E-08**	**7.80E-03**	**10.50**	**49.13**	**6.00**	**561.83**	**1.801**	**1.66**	**7.77**	**0.95**	**0.35**	**0.28**	**3,196**
Weekly (Seasonal) Average Summary (x4 wks)			**5 Plus (RB)**	**33.72**	**34.62**	**29.07**			**30.36**	**31.57**	**24.95**			**120.60**	**191.93**	**92.06**			**1.49E-01**	**2.88E-01**	**9.39E-02**			**10.38**	**33.78**	**6.41**			**1.62**	**5.27**	**1.00**			**3,198**

Seasonal Weekly % Average difference																																		
Week 1	*Spring*		**5 Plus (RB)**	0.92%	2.66%	-5.29%			1.25%	4.70%	-9.84%			-1.70%	22.83%	-8.88%			4.17%	132.29%	-86.74%			-4.56%	0.41%	-6.46%			-3.54%	1.71%	-5.22%			-6.20%
Week 2	*Summer*			-2.69%	-1.45%	-5.44%			-1.55%	0.77%	-1.72%			-12.84%	-5.45%	-46.08%			52.11%	28.70%	31.83%			-0.70%	21.97%	-2.73%			-5.08%	16.55%	-7.02%			5.19%
Week 3	*Autumn*			0.38%	1.32%	-2.77%			-0.02%	1.47%	-6.52%			4.49%	13.84%	-20.20%			9.67%	57.59%	-71.91%			3.01%	18.38%	-6.46%			4.37%	19.91%	-5.22%			1.04%
Week 4	*Winter*			1.04%	1.32%	-6.73%			0.26%	1.54%	-8.71%			8.69%	26.30%	2.77%			-54.70%	-9.40%	-75.81%			1.20%	45.43%	-6.46%			2.53%	47.31%	-5.22%			-0.04%

Abbreviations

Avge ***Average mean value of all arguments***
Max ***Maximum value within data set***
Min ***Minimum value within data set***
Var ***Variance from the average mean across the data set***
SD ***Standard Deviation from the average mean value across the data set***
N/A ***Volunteer Not Available***

Table 50 - Sensewear Armband Measured Values – Volunteer (RB)

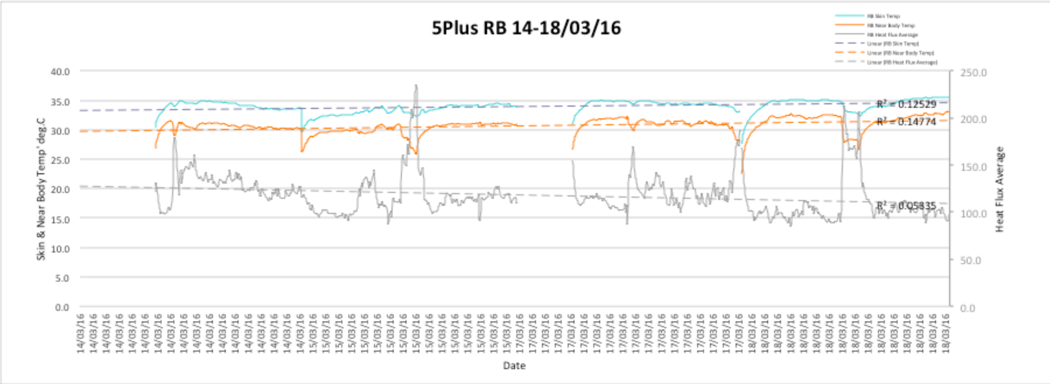


Fig. 104 – RB Seasonal Skin & Near Body Temperature and Heat Flux – March 2016 (Spring)

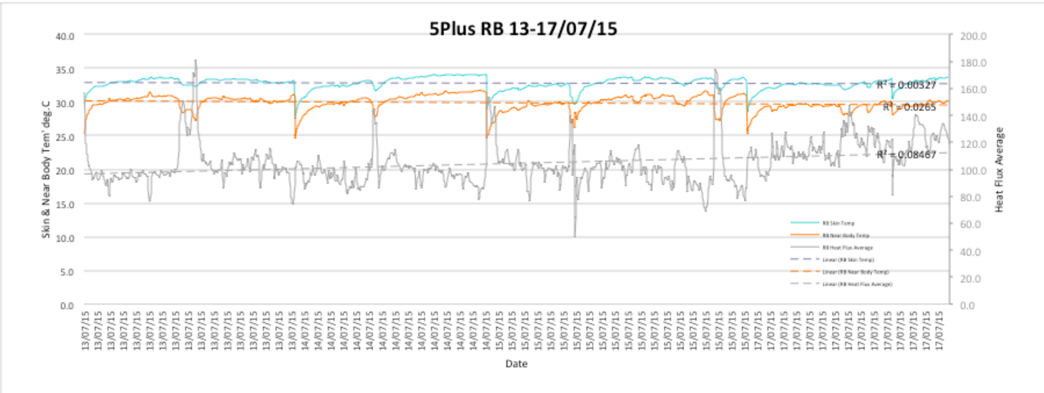


Fig. 105 – RB Seasonal Skin & Near Body Temperature and Heat Flux – July 2015 (Summer)

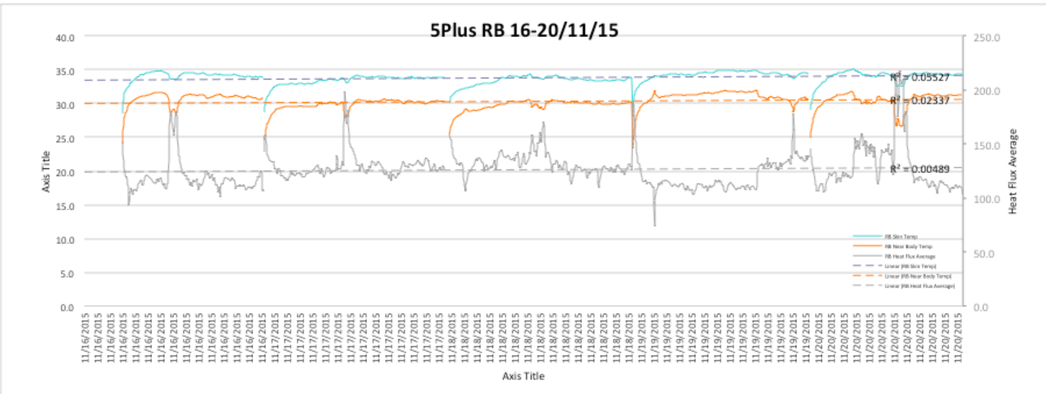


Fig. 106 – RB Seasonal Skin & Near Body Temperature and Heat Flux – November 2015 (Autumn)

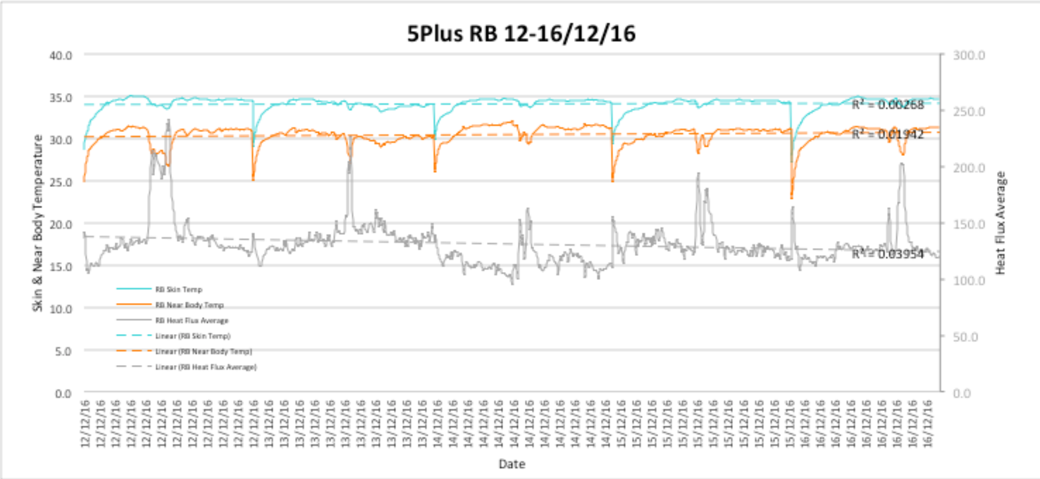


Fig. 107 – RB Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Fig's. 104-107 represents the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 51. As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier. Similar results were found with volunteer (CH, MHay & MHar)

Heat Flux average is a more variable set of values with greater R^2 values but with relatively low inclination of the trend line. The spring and winter periods indicate a slightly decreasing trend, however, summer and autumn indicate a relative level but increasing trend over the weekly period. Volunteer (RB) values indicate a very consistent set of values with excellent relationships to thermal skin and near body events. Events.

Fig's. 108-111 represents a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

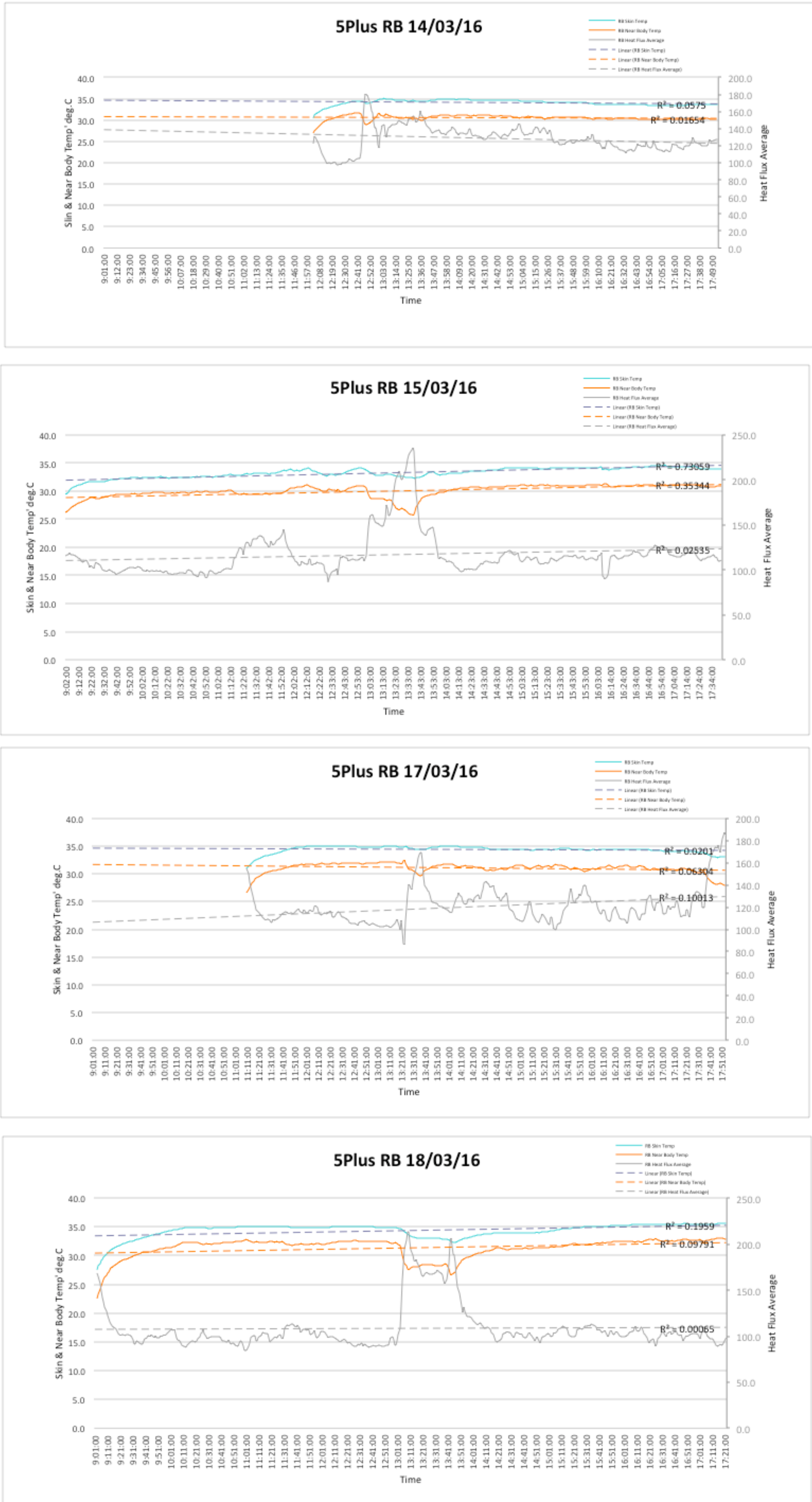


Fig. 108 – RB Daily Skin & Near Body Temperature and Heat Flux Values March 2016 (Spring)

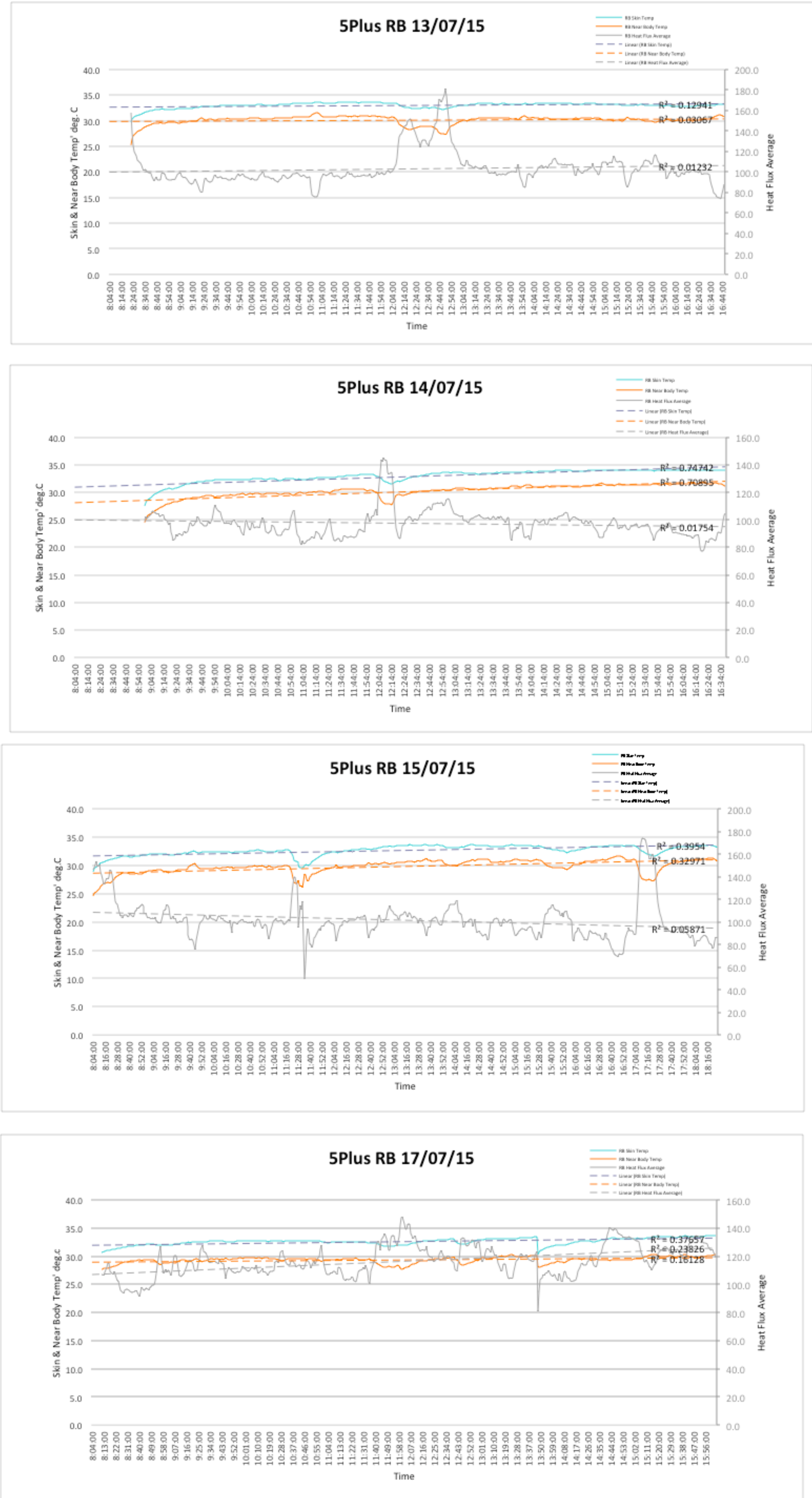


Fig. 109 – RB Daily Skin & Near Body Temperature and Heat Flux Values July 2015 (Summer)

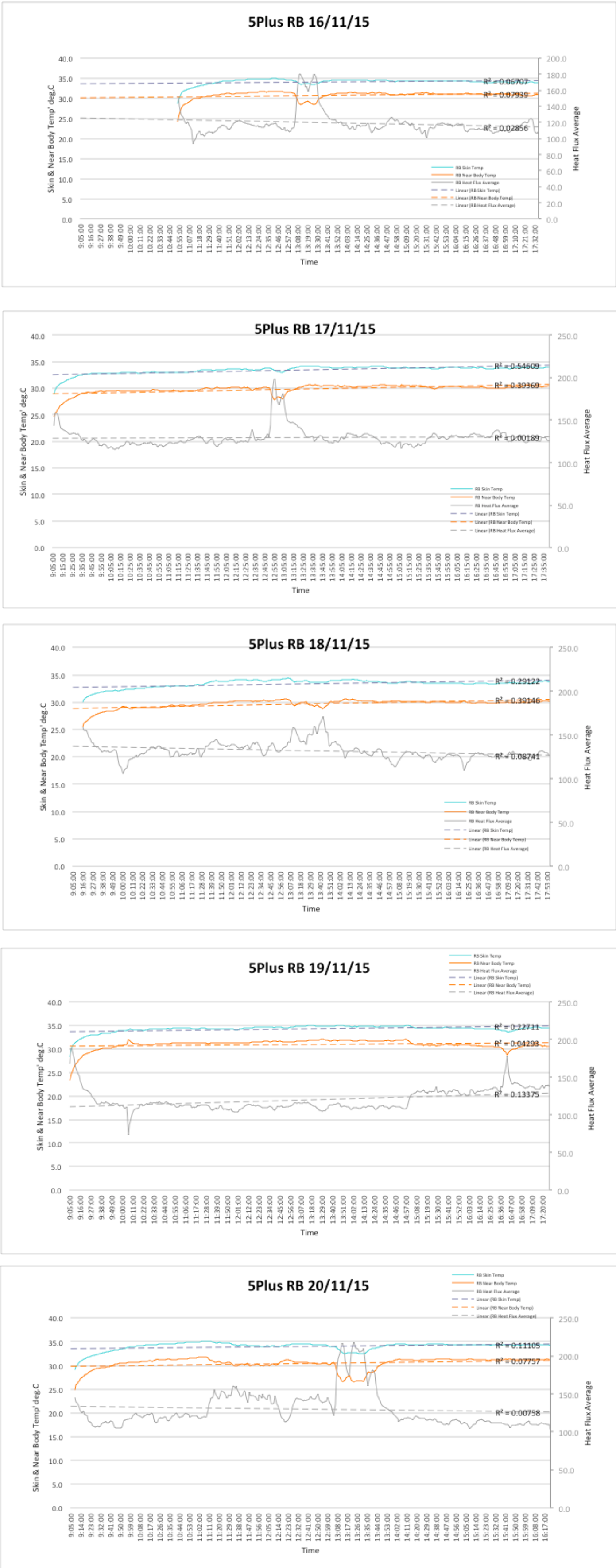
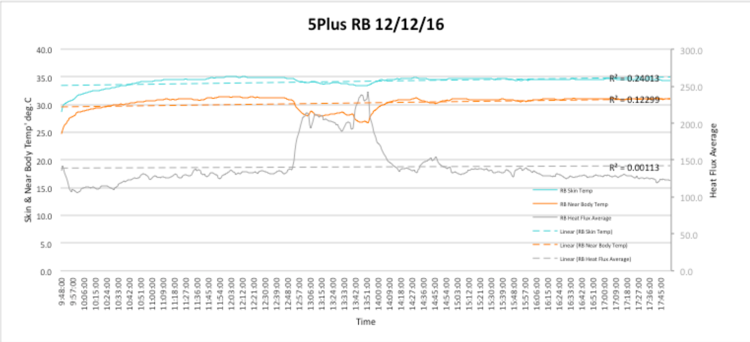
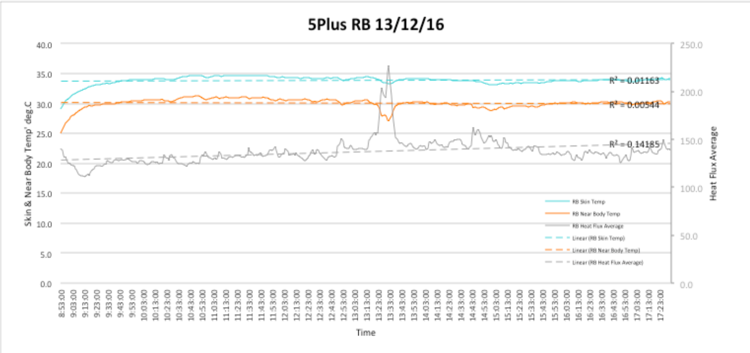
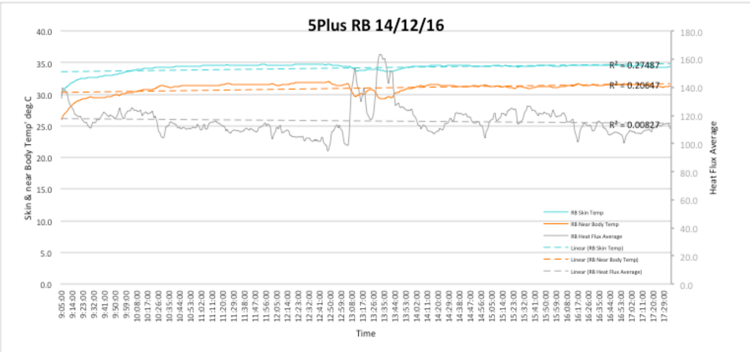
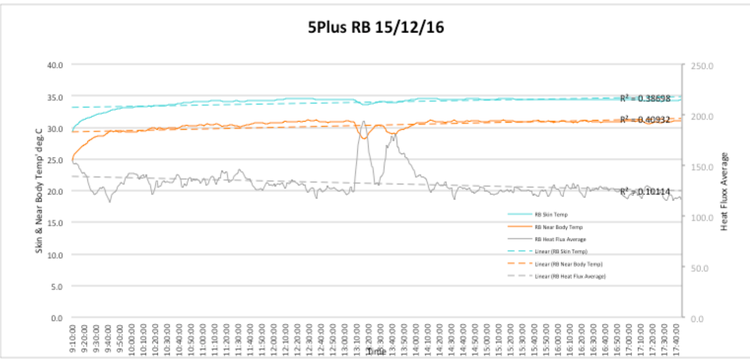


Fig. 110 – RB Daily Skin & Near Body Temperature and Heat Flux Values November 2015 (Autumn)









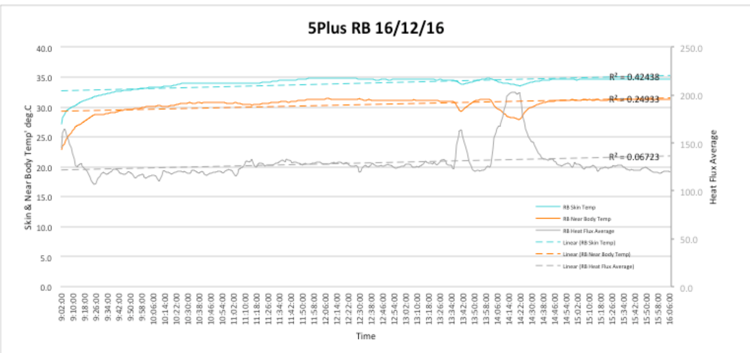


Fig. 111 – RB Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

Within each of Fig’s. 108-111, the Skin and Near Body temperature rises continually throughout the day as seen across other volunteers and within normal expected physical body temperature expectations. Heat flux average trends consistently level with only slight upwards or downwards inclination so a very consistent set of measurements. A sharp reduction or increase skin or near body temperature drives an opposite response from heat flux average value which is to be expected as a significant exchange in thermal exchange is experienced. This is consistent with all 5Plus volunteers.

Fig’s. 112-115 represents Galvanic Skin Response and indicate the equivalent seasonal periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead. The overall weekly trend for volunteer (RB) during Spring indicates a consistent downward trend Mon-Fri, however, Thursday indicates the only daily increase in GSR. The sharp increases in GSR are indicative of daily issues experienced either meetings or conflict situations, however, RB appears to be a consistently lease stressful individual over the daily measured period. Further ambient v physiological correlation analysis is provided within Chapter 6

The overall weekly trend for volunteer (RB) during ***spring,*** (Fig.112) indicates a consistent set of values and profiles similar to other volunteers. A reducing trend pattern is forming at 5Plus Architects with the volunteers displaying similar GSR trends. Gaps in the upper graph data are a result of cleansing the data during analysis. The initially daily sharp increase is not available during spring due to data cleansing and issues with the fitting of the armband. The values for Mon and Wed indicate significant stressors (GSR) values around the lunchtime period with very similar profile returns too much lower levels. Tues – Fri GSR values are very stable across the day and it is understood the volunteer was CAD drawing fro these periods and therefore significantly relaxed listening to music via headset.

The overall weekly trend for volunteer (RB) during ***summer,*** (Fig.113) is a downward trend. A significant stressor (GSR) value again exists around the Monday lunchtime period and has driven the graph to a larger axis scale. The daily values across other days remain consistent and to similar profiles. Other sharp increases in GSR levels are noted around typical break times. But again the overall weekly trend is downwards Mon-Fri albeit only slight in this volunteer’s case. The profiles are not as consistent to the other volunteers in terms of daily values, but this may a consequence of age and general demeanour being one of the younger staff members.

The overall weekly trend for volunteer (RB) during ***autumn,*** (Fig.114) indicates for Volunteer (RB) a rare example of an upward GSR trend over the measured weekly period. Time dependant events can be consistently noted over the lunchtime period as the volunteer leaves the armband on during lunchtime and leaving the building. Thurs a particularly eventful day would appear to be a very stressful period with a consistent hourly increase. This increase is potentially as a consequence of meeting a project deadline a return to more expected normal levels of GSR on the Fri.

The overall weekly trend for volunteer (RB) during ***winter,*** (Fig.115) indicates again a number of time dependant series of events around the lunchtime period as experienced across other seasonal periods. The daily profiles have become more consistent to other volunteer profiles and to similar values. Following the increased GSR event a return to a similar previous level is noted within approx. 1hr – 1.5hrs, this is relatively consistent with other volunteer profiles. An overall reduction in GSR trend value is again noted across the seasonal period.

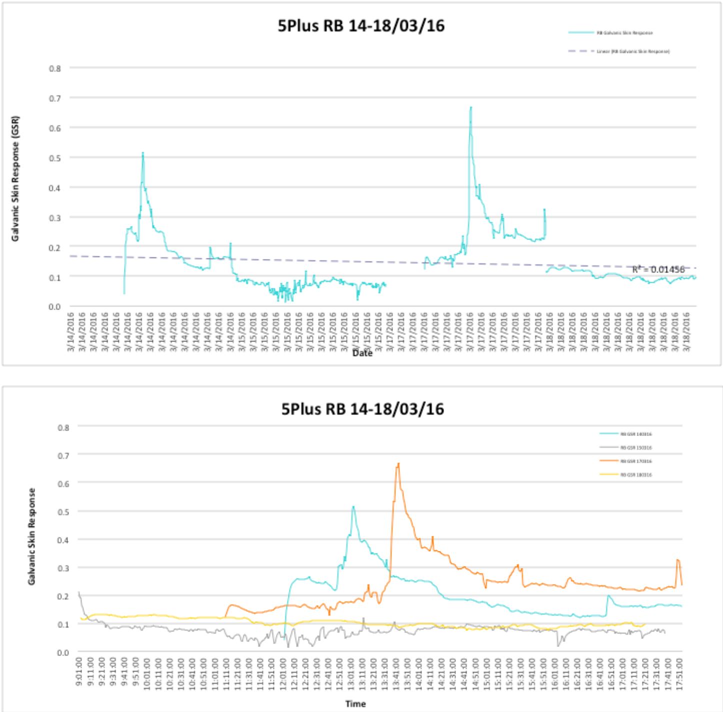


Fig. 112 – RB GSR Daily and Weekly Measured Values March 2016 (Spring)

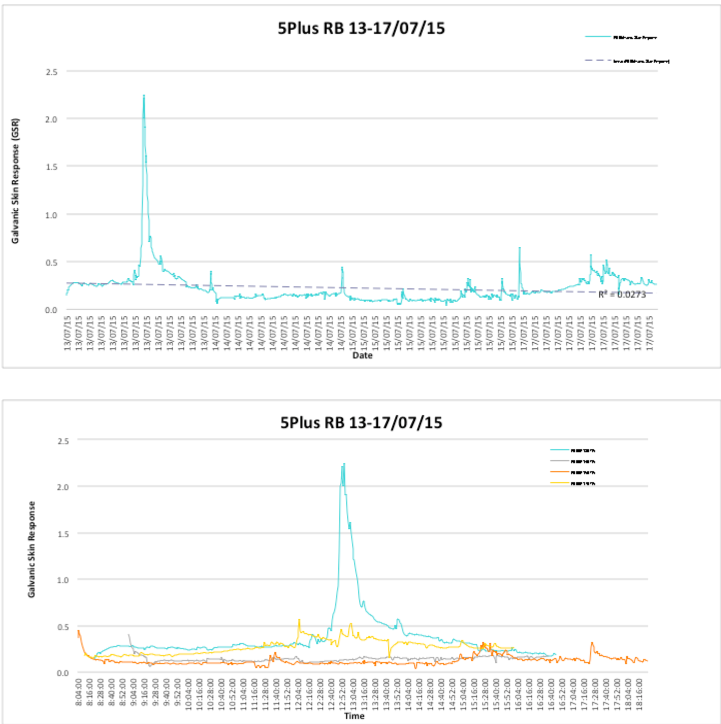


Fig. 113 – RB GSR Daily and Weekly Measured Values July 2015 (Summer)

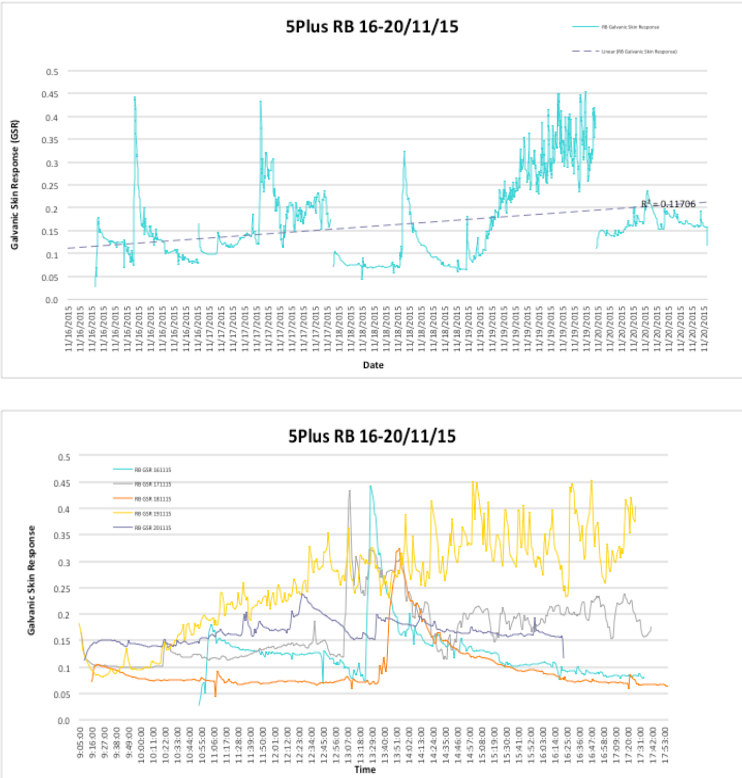


Fig. 114 – RB GSR Daily and Weekly Measured Values November 2015 (Autumn)

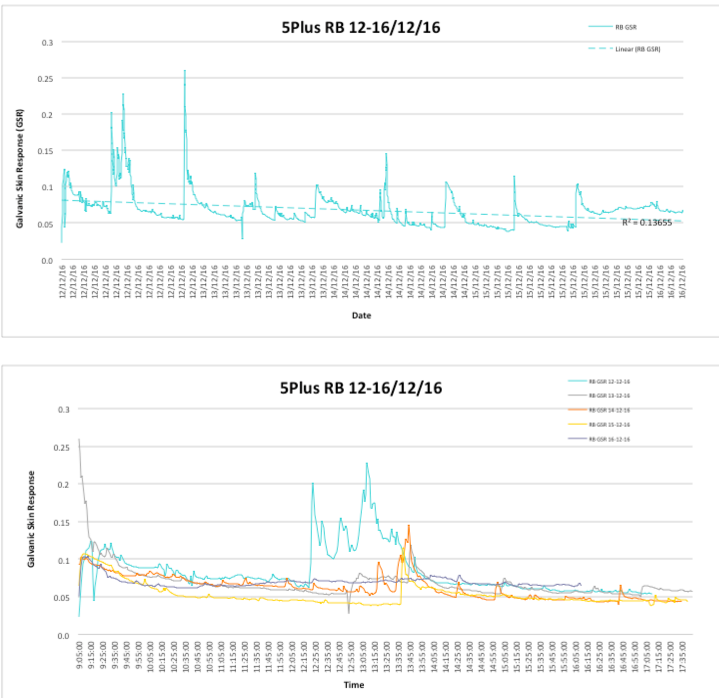


Fig. 115 – RB GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.5 BSRIA Volunteer 1 (MA-H)

Table 51 indicates the measured data obtained from volunteer (MA-H). A non-smoking female of weight 57.6kg height 162.2cm and BMI of 21.8. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent. Volunteer (MA-H) was a consistent and excellent participant with a total armband on body time of 136hrs 41mins (85%) from an expected research time of 160 hrs (8hrs/day x5days/wk x4 seasonal periods). The volunteer was not available 09/12/16. The data is considered sufficient for analysis.

The average skin temperature noted within Table 51 across spring, summer, autumn and winter would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. Variance and standard deviation are small supporting the possibility that both parameters would be suitable for building system feedback acceptance. The Weekly (Seasonal) Average Skin Temperature of 32.12 deg.C applied to each seasonal weekly average value indicates a 0.11% increase during Spring; 0.98% increase during Summer; 0.72% increase during Autumn; and -2.26% decrease during Winter. Across all x4 seasons Maximum values range -1.61% during winter to 5.66% during summer with Minimum values ranging between -27.68% during winter to 2.82% during summer.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 29.39 deg.C applied to each seasonal weekly average value indicates a -0.41% decrease during Spring; 2.44% increase during Summer; 0.20% increase during Autumn; and -2.78% decrease during Winter. Across all x4 seasons Maximum figures range -0.07% during winter to 8.15% during summer with Minimum figures ranging between -0.08% during autumn to 0.05% during summer.

Heat flux average values although relatively consistent overall between the seasons the graphical representation, this is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer.

Significant variance exists seasonally, however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 97.39 W/m^2 applied to each seasonal weekly average value indicates a 5.40% increase during Spring; -14.78% decrease during Summer; 6.18% increase during Autumn; and 2.49% increase during Winter. Across all x4 seasons Maximum figures range 28.30% spring to -0.45% summer with Minimum figures ranging between -255.83% summer to -15.74 during autumn.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (μS) of 6.75E-02 applied to each seasonal weekly average value indicates a -14.66% decrease during Spring; 12.42% increase during Summer; -9.05% decrease during Autumn; and 14.11% increase during Winter. Across all x4 seasons Maximum figures range 77.90% during summer to 2.40% during autumn with Minimum figures ranging between -48.37% during autumn to -32.88% during summer and winter.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 6.28 (KJ) applied to each seasonal weekly average value indicates a -0.91% decrease during Spring; -3.33% decrease during Summer; -0.64% decrease during Autumn; and 6.10% increase during Winter. Across all x4 season's Maximum figures range 27.83% during spring to 1.58% during summer with Minimum values ranging between -4.19% during winter to 0.13% during spring. The Weekly (Seasonal) Average Metabolic Equivalent value 1.56 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -0.58% decrease during Spring; -3.01% decrease during Summer; -1.57% increase during Autumn; and 6.46% increase during winter. Across all x4 season's Maximum figures range 1.88% during summer to 28.21% spring with Minimum figures ranging between -4.33% during autumn to 0.46% during summer. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteer - MA-H

BSRIA - Bracknell - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)					Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	25/04/16		5:07	30.86	31.45	27.51	0.37	0.61	28.31	29.27	24.22	28.31	0.75	89.89	124.27	66.29	83.02	9.11	7.62E-02	1.56E-01	1.03E-02	1.80E-04	1.34E-02	6.15	24.04	3.82	16.89	4.11	1.53	5.99	0.95	1.05	1.02	2,812
Tues	26/04/16		8:39	31.40	32.32	28.22	0.25	0.50	28.49	29.34	24.60	0.49	0.70	103.02	160.53	83.12	166.53	12.90	6.28E-02	1.26E-01	1.03E-02	2.21E-04	1.49E-02	6.23	27.63	4.08	12.74	3.57	1.55	6.88	1.01	0.79	0.89	3,556
Wed	27/04/16		6:36	32.04	33.32	29.08	0.65	0.81	28.48	29.70	25.32	0.90	0.95	126.70	186.84	109.50	142.64	11.94	4.78E-02	1.05E-01	1.25E-02	1.48E-04	1.22E-02	6.75	23.48	3.89	13.62	3.69	1.68	5.84	0.97	0.84	0.92	3,777
Thurs	28/04/16	MA-H	8:47	33.40	34.75	30.19	0.57	0.76	31.03	33.39	27.07	1.37	1.17	84.54	163.43	32.53	405.47	20.14	5.34E-02	1.11E-01	9.52E-03	1.57E-04	1.25E-02	5.94	26.44	3.80	12.47	3.53	1.48	6.58	0.95	0.77	0.88	3,071
Fri	29/04/16		7:07	33.10	34.07	29.76	0.49	0.70	30.05	31.14	25.24	0.57	0.76	109.12	157.40	90.13	80.85	8.99	4.80E-02	8.21E-02	1.69E-02	4.36E-05	6.61E-03	6.06	24.44	3.89	13.73	3.71	1.51	6.08	0.97	0.85	0.92	2,961
Week 1	**Spring**		**36:16**	**32.16**	**34.75**	**27.51**	**0.02**	**0.11**	**29.27**	**33.39**	**24.22**	**120.85**	**0.17**	**102.65**	**186.84**	**32.53**	**14,311.26**	**4.06**	**5.76E-02**	**1.56E-01**	**9.52E-03**	**3.47E-09**	**2.82E-03**	**6.23**	**27.63**	**3.80**	**2.49**	**0.21**	**1.55**	**6.88**	**0.95**	**0.01**	**0.05**	**3,235**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	15/08/16		8:07	32.27	33.23	29.55	0.25	0.50	29.98	32.41	28.03	0.38	0.62	81.33	117.24	23.86	124.89	11.18	9.44E-02	2.16E-01	2.42E-02	4.08E-04	2.02E-02	5.74	20.22	3.94	8.09	2.84	1.43	5.03	0.98	0.50	0.71	2,825
Tues	16/08/16		8:40	32.84	35.21	30.84	1.30	1.14	30.76	33.30	27.67	1.53	1.24	73.94	129.85	15.54	189.15	13.75	8.46E-02	2.48E-01	8.06E-03	7.10E-04	2.67E-02	6.21	21.96	4.01	10.47	3.24	1.55	5.47	1.00	0.65	0.81	4,136
Wed	17/08/16		7:27	32.35	33.32	30.19	0.21	0.46	30.15	31.47	28.30	0.41	0.64	78.02	118.49	44.59	139.42	11.81	7.80E-02	2.35E-01	2.42E-02	7.71E-04	2.78E-02	6.36	21.83	4.05	9.03	3.00	1.58	5.43	1.01	0.56	0.75	3,083
Thurs	18/08/16	MA-H	7:38	31.40	33.15	30.06	0.69	0.83	28.86	33.75	27.09	1.48	1.22	89.56	142.40	-83.38	938.26	30.63	6.41E-02	8.13E-02	1.83E-02	1.42E-04	1.19E-02	6.05	19.82	3.98	5.75	2.40	1.50	4.93	0.99	0.36	0.60	2,070
Fri	19/08/16		6:36	33.34	34.48	29.29	0.60	0.77	30.81	33.10	26.41	1.01	1.01	90.49	144.97	45.15	210.39	14.50	5.85E-02	8.79E-02	1.17E-02	1.68E-04	1.30E-02	6.02	17.62	4.13	3.82	1.95	1.50	4.39	1.03	0.24	0.49	2,385
Week 2	**Summer**		**38:28**	**32.44**	**35.21**	**29.29**	**0.15**	**0.25**	**30.11**	**33.75**	**26.41**	**0.25**	**0.27**	**83.00**	**144.97**	**-83.38**	**96,410.63**	**7.23**	**7.59E-02**	**2.48E-01**	**8.06E-03**	**6.93E-08**	**6.62E-03**	**6.07**	**21.96**	**3.94**	**5.62**	**0.46**	**1.51**	**5.47**	**0.98**	**0.02**	**0.11**	**2,900**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	14/09/15		6:24	32.09	33.32	27.59	0.36	0.60	28.89	31.10	23.00	0.85	0.92	113.92	165.93	78.74	381.25	19.53	5.02E-02	7.47E-02	7.33E-03	3.27E-04	1.81E-02	6.82	20.19	3.82	10.16	3.19	1.67	4.95	0.94	0.61	0.78	2,845
Tues	15/09/15		3:17	33.09	34.52	29.59	1.97	1.40	30.64	32.99	24.40	3.12	1.77	87.29	179.62	45.09	509.21	22.57	6.11E-02	1.27E-01	8.79E-03	3.15E-04	1.77E-02	5.61	12.69	4.17	1.03	1.01	1.38	3.11	1.02	0.06	0.25	243
Wed	16/09/15		8:20	33.06	34.14	29.15	0.52	0.72	30.36	32.32	25.99	0.83	0.91	96.56	126.39	54.54	181.44	13.47	6.11E-02	1.27E-01	8.79E-03	3.15E-04	1.77E-02	6.57	26.11	3.93	16.96	4.12	1.61	6.40	0.96	1.02	1.01	5,030
Thurs	17/09/15	MA-H	8:55	31.44	32.77	28.07	0.30	0.55	28.06	29.25	23.79	0.39	0.62	119.83	145.44	95.09	68.74	8.29	4.99E-02	1.41E-01	1.17E-02	2.32E-04	1.52E-02	6.62	19.16	3.97	10.48	3.24	1.62	4.70	0.97	0.63	0.79	3,926
Fri	18/09/15		06:00	32.12	33.57	27.19	0.90	0.95	29.32	30.75	24.44	0.83	0.91	99.48	125.79	78.24	71.21	8.44	8.48E-02	1.28E-01	1.76E-02	1.65E-04	1.28E-02	5.60	18.00	3.90	4.55	2.13	1.39	4.48	0.97	0.28	0.53	1,337
Week 3	**Autumn**		**32:56**	**32.36**	**34.52**	**27.19**	**0.38**	**0.31**	**29.45**	**32.99**	**23.00**	**0.95**	**0.39**	**103.41**	**179.62**	**45.09**	**30,729.61**	**5.77**	**6.14E-02**	**1.41E-01**	**7.33E-03**	**3.95E-09**	**2.02E-03**	**6.24**	**26.11**	**3.82**	**29.90**	**1.07**	**1.53**	**6.40**	**0.94**	**0.11**	**0.26**	**2,676**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	05/12/16		7:39	31.49	32.79	26.70	0.97	0.99	28.29	29.59	21.35	1.64	1.28	113.15	176.17	89.00	210.94	14.52	6.72E-02	1.03E-01	1.90E-02	2.24E-04	1.50E-02	6.55	22.41	3.95	10.90	3.30	1.63	5.58	0.98	0.68	0.82	3,682
Tues	06/12/16		8:12	31.08	32.21	30.04	0.20	0.45	28.35	29.49	26.70	0.27	0.52	96.47	130.70	59.61	210.32	14.50	5.89E-02	1.14E-01	1.32E-02	1.65E-04	1.28E-02	6.86	23.69	3.77	14.01	3.74	1.71	5.90	0.94	0.87	0.93	5,754
Wed	07/12/16		8:03	31.89	32.74	20.61	0.95	0.97	29.39	31.18	19.80	1.16	1.08	89.05	135.98	20.50	296.30	17.21	9.61E-02	1.14E-01	9.52E-03	2.23E-04	1.49E-02	6.11	19.30	3.85	9.62	3.10	1.52	4.80	0.96	0.60	0.77	3,291
Thurs	08/12/16	MA-H	5:07	31.13	31.82	27.69	0.26	0.51	28.28	29.38	24.13	0.57	0.76	100.59	135.49	68.58	149.69	12.23	8.60E-02	2.46E-01	2.78E-02	9.22E-04	3.04E-02	7.14	21.70	3.90	14.66	3.83	1.78	5.40	0.97	0.91	0.95	4,009
Fri	09/12/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	**Winter**		**29:01**	**31.40**	**32.79**	**20.61**	**0.13**	**0.25**	**28.58**	**31.18**	**19.80**	**0.28**	**0.29**	**99.81**	**176.17**	**20.50**	**2,725.10**	**1.76**	**7.71E-02**	**2.46E-01**	**9.52E-03**	**9.71E-08**	**7.03E-03**	**6.67**	**23.69**	**3.77**	**4.41**	**0.30**	**1.66**	**5.90**	**0.94**	**0.02**	**0.08**	**4,184**
Weekly (Seasonal) Average Summary (x4 wks)			**BSRIA (MA-H)**	**32.12**	**33.33**	**28.49**			**29.39**	**31.21**	**25.13**			**97.39**	**145.63**	**53.51**			**6.75E-02**	**1.38E-01**	**1.42E-02**			**6.28**	**21.62**	**3.94**			**1.56**	**5.37**	**0.98**			**3,249**

Seasonal Weekly % Average difference																																		
Week 1	*Spring*		**BSRIA (MA-H)**	0.11%	4.28%	-3.46%			-0.41%	7.00%	-0.04			5.40%	28.30%	-39.21%			-14.66%	13.01%	-32.88%			-0.91%	27.83%	-3.61%			-0.58%	28.21%	-3.29%			-0.41%
Week 2	*Summer*			0.98%	5.66%	2.82%			2.44%	8.15%	0.05			-14.78%	-0.45%	-255.83%			12.42%	79.90%	-43.21%			-3.33%	1.58%	0.13%			-3.01%	1.88%	0.46%			-10.74%
Week 3	*Autumn*			0.72%	3.59%	-4.55%			0.20%	5.71%	-0.08			6.18%	23.34%	-15.74%			-9.05%	2.40%	-48.37%			-0.64%	20.80%	-3.15%			-1.57%	19.27%	-4.33%			-17.63%
Week 4	*Winter*			-2.26%	-1.61%	-27.68%			-2.78%	-0.07%	-0.21			2.49%	20.97%	-61.69%			14.11%	77.77%	-32.88%			6.10%	9.58%	-4.19%			6.46%	9.90%	-3.88%			28.78%

Abbreviations

Avge ***Average mean value of all arguments***
Max ***Maximum value within data set***
Min ***Minimum value within data set***
Var ***Variance from the average mean across the data set***
SD ***Standard Deviation from the average mean value across all data sets***
N/A ***Volunteer Not Available***

Table 51 - Sensewear Armband Measured Values – Volunteer (MA-H)

Fig's. 116-119 represents the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 52. As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier.

Heat Flux average is a more variable set of values with greater R^2 values and significant inclination of the trend line. Spring, summer and winter periods indicate a slight increasing trend, however, the winter period indicates a more downward trend. An analysis of ambient relationships is provided within Chapter 6.

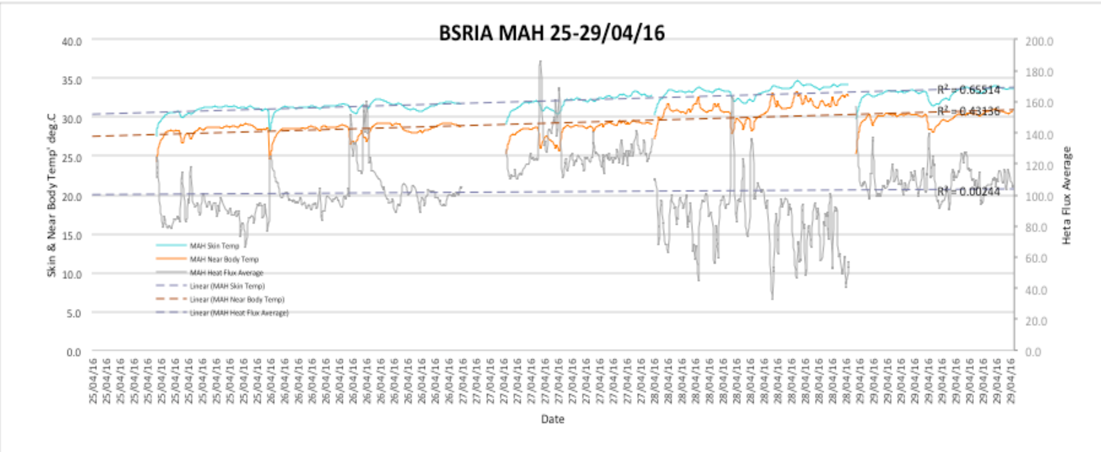


Fig. 116 – MA-H Seasonal Skin & Near Body Temperature and Heat Flux – April 2016 (Spring)

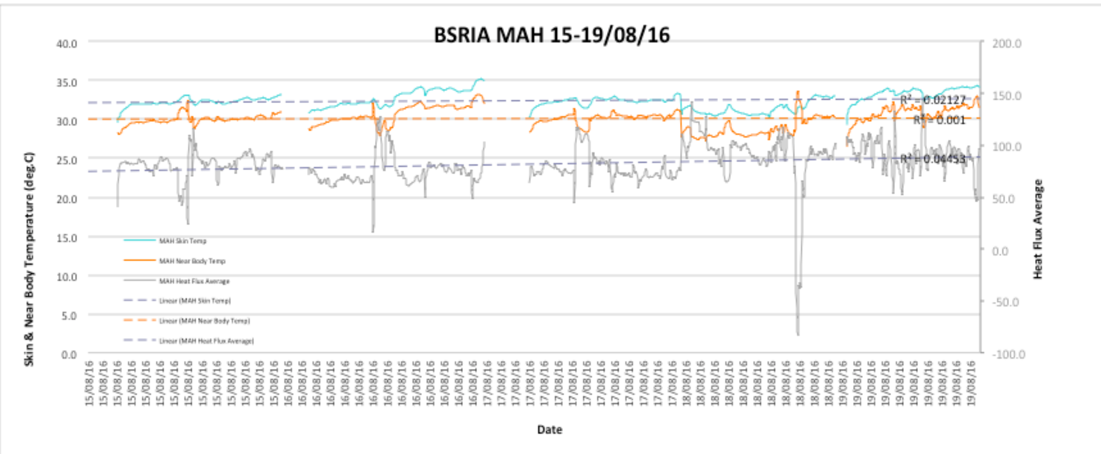


Fig. 117 – MA-H Seasonal Skin & Near Body Temperature and Heat Flux – Aug 2016 (Summer)

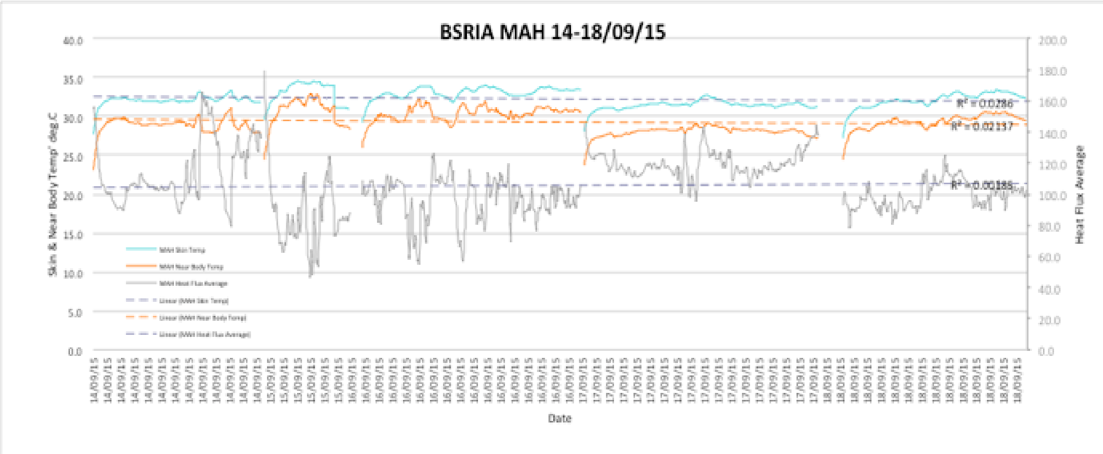


Fig.118 – Seasonal Skin & Near Body Temperature and Heat Flux – September 2015 (Autumn)

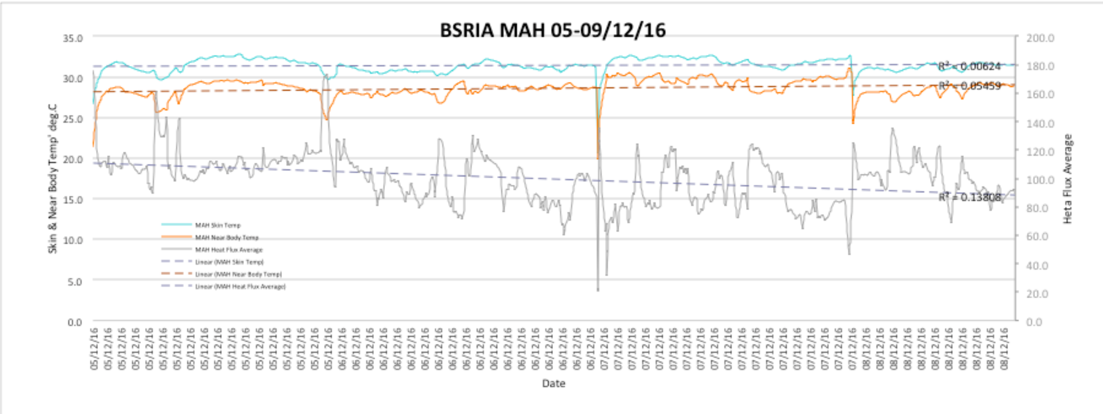


Fig.119 – MA-H Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Within each of Fig's 116-119 the Skin and Near Body temperature rises continually throughout the day as seen across other volunteers and within normal expected physical body temperature expectations. Heat flux average trends consistently upwards at varying degrees of R^2 for spring, summer and autumn, however, downwards for winter. A sharp reduction or increase skin or near body temperature drives an opposite response from heat flux average value which is to be expected as a significant exchange in thermal exchange is experienced.

Fig's. 120-123 represents a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

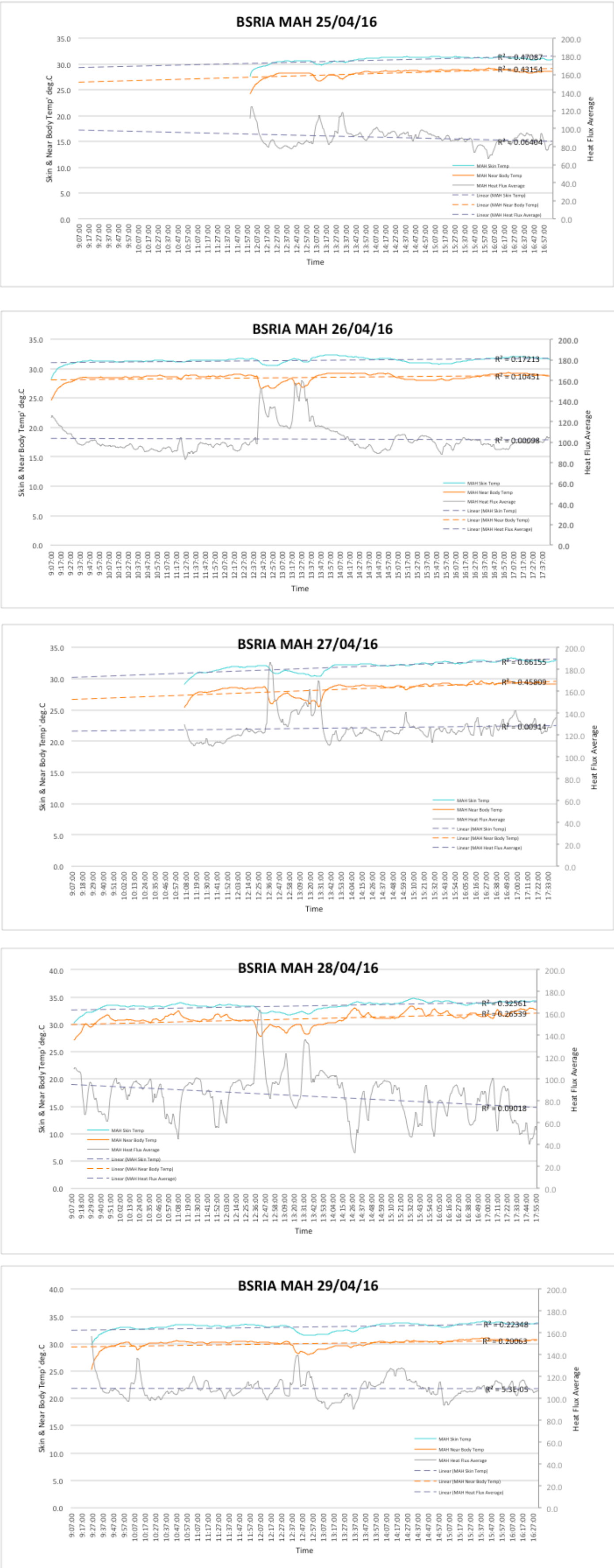
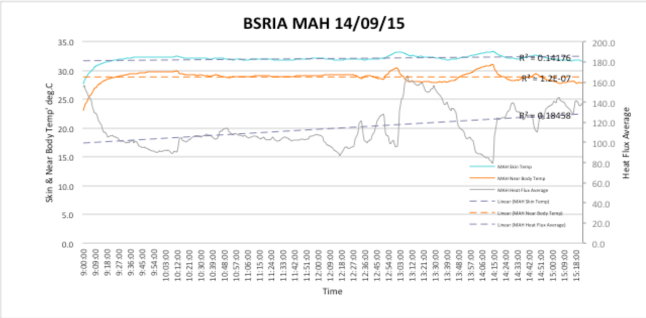
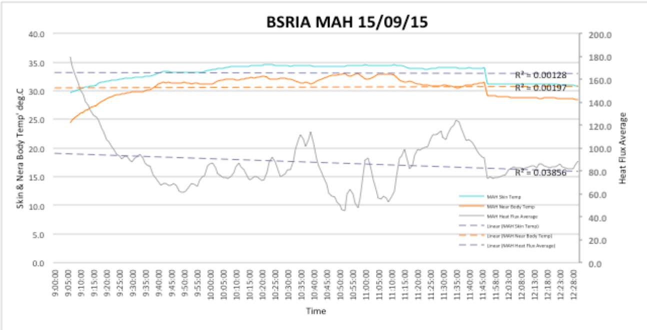
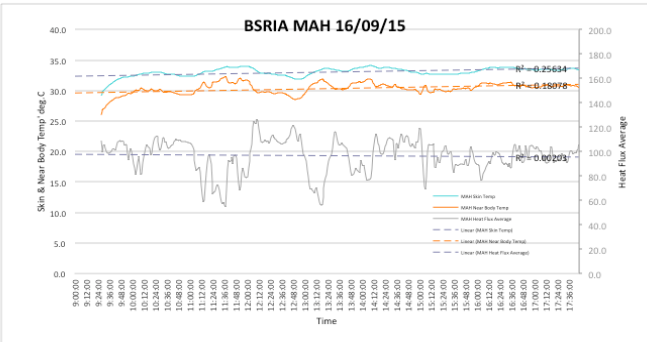


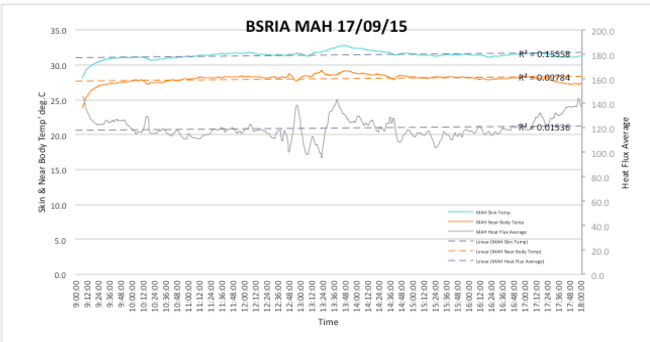
Fig. 120 – MA-H Daily Skin & Near Body Temperature and Heat Flux Values April 2016 (Spring)

Fig. 121 – MA-H Daily Skin & Near Body Temperature and Heat Flux Values August 2016 (Summer)









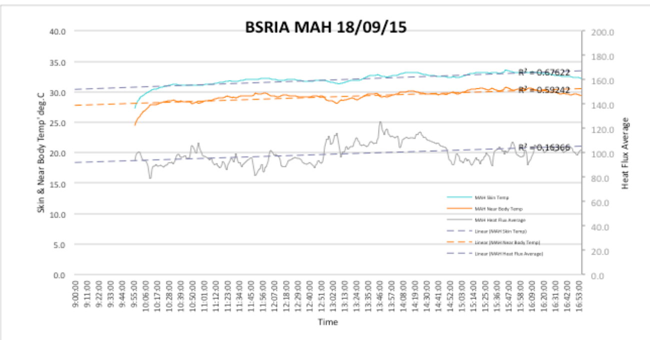


Fig. 122 – MA-H Daily Skin & Near Body Temperature and Heat Flux Values September 2015 (Autumn)

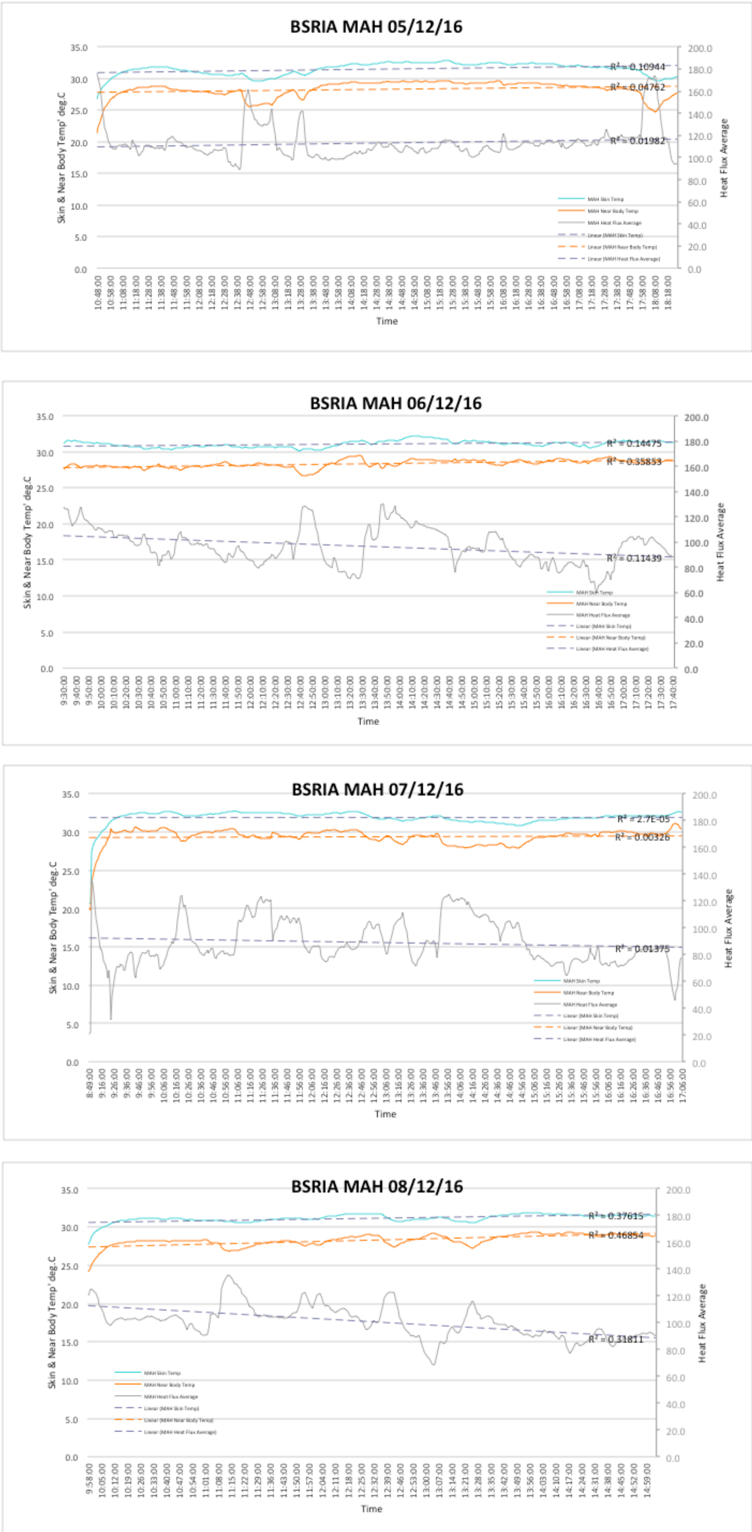
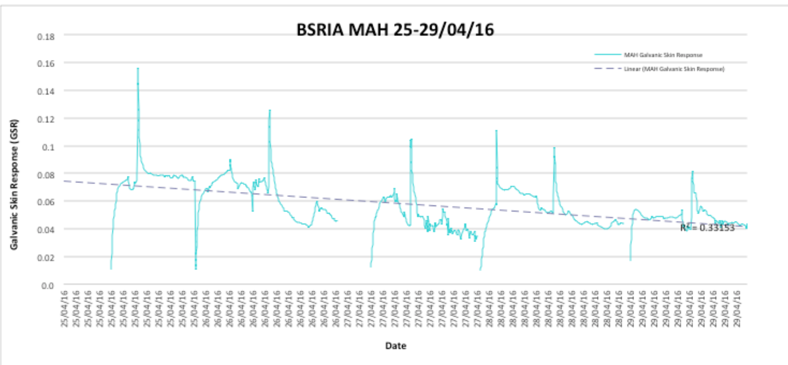


Fig.123 – MA-H Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

Fig's. 124-127 represents Galvanic Skin Response (GSR) and indicates the equivalent seasonal periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead. The overall weekly trend for volunteer (MA-H) during spring indicates a consistent downward trend Mon-Fri. During the remaining seasons there appears a significant weekly upward trend which is against the measured norm across other volunteers. The sharp increases in GSR are indicative of daily issues experienced either meetings or conflict situations, however, (MA-H) appears to be a consistently lease stressful individual over the daily measured period however, consistent lunchtime GSR event values are recognised which then require a period of time to normalise. Further ambient v physiological correlation analysis is provided within Chapter 6.

The overall weekly trend for volunteer (MA-H) during ***spring*** (Fig. 124) indicates a consistent downward trend Mon-Fri. The sharp increases in GSR are indicative of daily issues experienced either meetings or conflict situations, however, (MA-H) appears to be a consistently lease stressful individual over the daily measured period however, consistent lunchtime GSR event values are recognised which then require a period of time to normalise. The overall weekly trend for volunteer (MA-H) during ***summer*** (Fig. 125) indicates a consistent downward trend Mon-Fri. The overall weekly trend for volunteer (MA-H) during autumn (Fig 125) indicates a consistent upward trend Mon-Fri. The overall weekly trend for volunteer (MA-H) during winter (Fig.127) again indicates a consistent upward trend Mon-Fri.



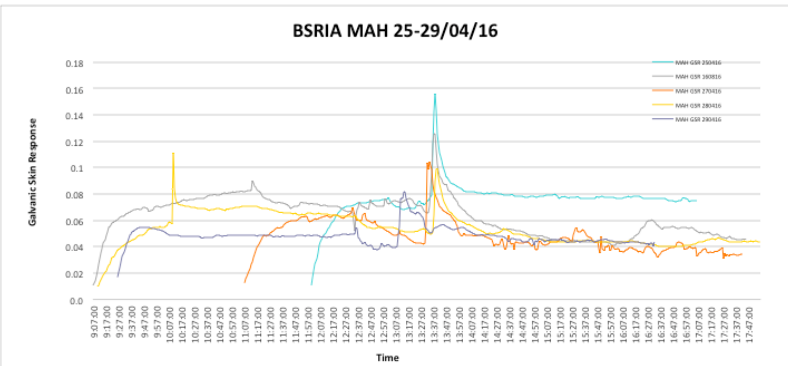


Fig 124. – MA-H GSR Daily and Weekly Measured Values April 2016 (Spring)

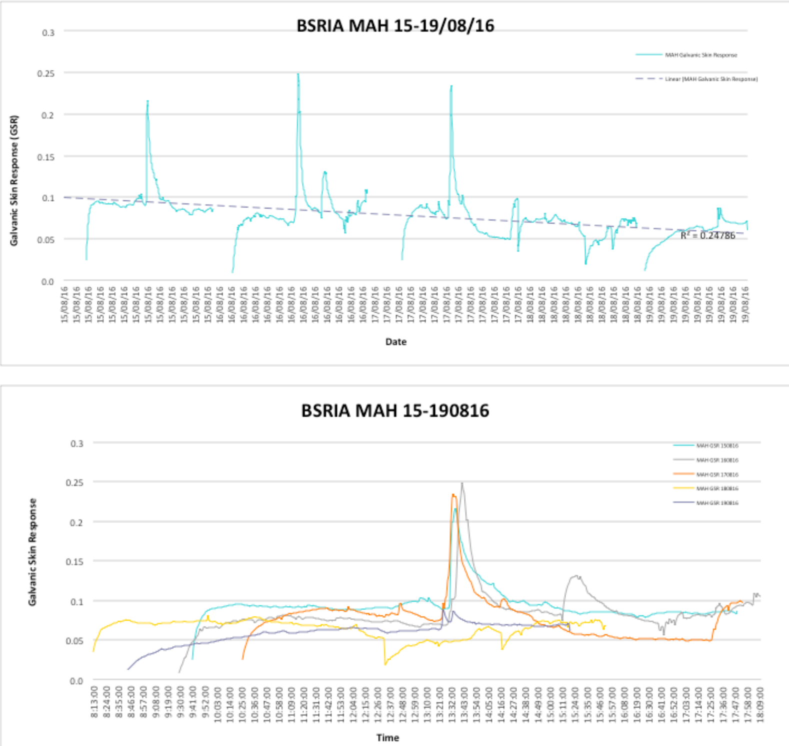


Fig. 125 – MA-H GSR Daily and Weekly Measured Values August 2016 (Summer)

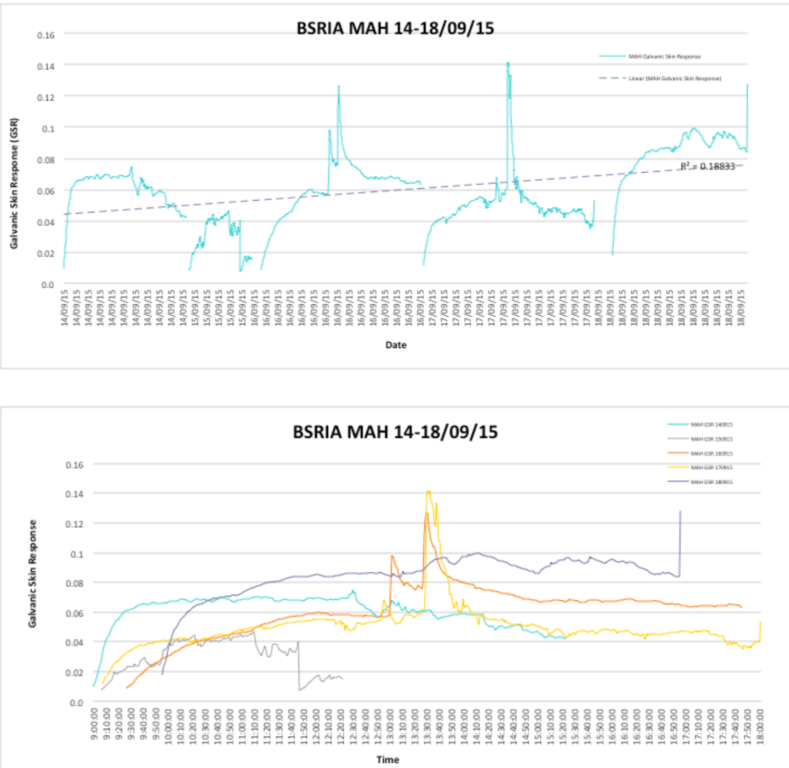


Fig. 126 – MA-H GSR Daily and Weekly Measured Values August 2015 (Autumn)

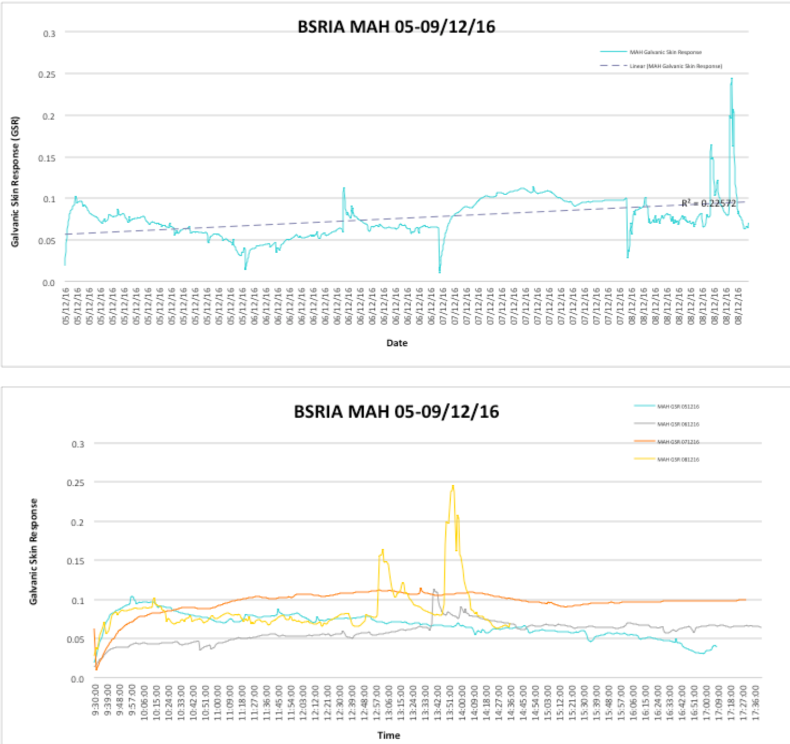


Fig. 127 – MA-H GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.6 BSRIA Volunteer 1 (IW)

Table 52 indicates the measured data obtained from volunteer (IW). A non-smoking male of weight 114.8kg height 170.2cm and BMI of 39.6. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent.

Volunteer (IW) was a consistent and good participant with a total armband on body time of 92hrs 24mins (58%) from an expected research time of 160 hrs (8hrs/day x5days/wk x4 seasonal periods). The data is considered sufficient for analysis. The volunteer was not available 29/04/16; 16/08/16; 14-16/09/15; 05/12/16; 07/12/16 and 09/12/16.

The average skin temperature noted within Table 52 across spring, summer and autumn would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. Variance and standard deviation are small supporting the possibility that both parameters would be suitable for building system feedback acceptance. The Weekly (Seasonal) Average Skin Temperature of 32.48 deg.C applied to each seasonal weekly average value indicates a -0.02% decrease during Spring; 1.62% increase during Summer; -2.23% decrease during Autumn; and -0.96% decrease during Winter. Across all x4 seasons Maximum values range -0.66% during autumn to 8.32% during spring with Minimum values ranging between -8.03% during autumn to 0.01% during winter.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 29.61 deg.C applied to each seasonal weekly average value indicates a -0.31% decrease during Spring; 2.78% increase during Summer; -3.09% decrease during Autumn; and -1.04% decrease during Winter. Across all x4 seasons Maximum figures range -5.31% during autumn to 19.64% during spring with Minimum figures ranging between -15.93% during spring to 6.40% during summer.

Heat flux average values although relatively consistent overall between the seasons the graphical representation would propose that this physiological measurement is not sufficiently accurate to use within any potential feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 102.56 W/m^2 applied to each seasonal weekly average value indicates a 2.51% increase during Spring; -13.43% decrease during Summer; 14.18% increase during Autumn; and -0.59% decrease during Winter. Across all x4 seasons Maximum figures range -17.93% summer to 27.15% spring with Minimum figures ranging between -192.70% spring to 54.31% during autumn.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (μS) of 1.74E-01 applied to each seasonal weekly average value indicates a -33.86% decrease during Spring; 37.53% increase during Summer; 14.81% increase during Autumn; and -22.13% decrease during winter. Across all x4 seasons Maximum figures range 103.74%

during summer to -24.53% during winter with Minimum figures ranging between -63.08% during summer to 3.38% during autumn.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 10.65 (KJ) applied to each seasonal weekly average value indicates a -0.69% decrease during Spring; -0.09% decrease during Summer; 2.36% increase during Autumn; and -0.8% increase during Winter. Across all x4 season's Maximum figures range 14.89% during summer to 9.64% during winter with Minimum values ranging between -4.56% during spring to 1.38% during winter. The Weekly (Seasonal) Average Metabolic Equivalent value 1.33 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -0.69% decrease during Spring; -0.09% decrease during Summer; 2.36% increase during Autumn; and -0.8% increase during Winter. Across all x4 season's Maximum figures range 14.89% during summer to 9.64% during winter with Minimum values ranging between -4.56% during spring to 1.38% during winter. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteer - IW

BSRIA - Bracknell - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)					Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	25/04/16	IW	3:08	31.43	33.37	26.90	1.36	1.17	28.65	30.47	20.61	2.49	1.58	97.95	206.66	80.69	336.87	18.35	9.94E-02	1.46E-01	1.10E-02	8.31E-04	2.88E-02	9.80	15.18	6.67	1.87	1.37	1.22	1.90	0.83	0.03	0.17	165
Tues	26/04/16		9:32	32.44	34.52	30.28	0.85	0.92	29.31	31.42	26.94	1.06	1.03	111.52	157.92	83.68	118.26	10.87	9.11E-02	2.10E-01	8.06E-03	2.76E-03	5.26E-02	10.62	33.31	6.68	15.29	3.91	1.33	4.16	0.83	0.24	0.49	2,058
Wed	27/04/16		9:24	32.70	34.16	27.44	0.98	0.99	29.56	31.86	22.62	1.41	1.19	112.22	169.14	81.61	177.29	13.31	1.29E-01	2.34E-01	7.33E-03	1.80E-03	4.24E-02	10.40	31.18	6.38	13.85	3.72	1.30	3.90	0.80	0.22	0.46	2,503
Thurs	28/04/16		6:03	33.33	36.88	29.15	2.26	1.50	30.56	38.20	24.64	4.35	2.09	98.84	183.26	-57.12	1,003.27	31.67	1.40E-01	3.12E-01	1.61E-02	2.82E-03	5.31E-02	11.50	33.80	6.92	37.47	6.12	1.44	4.22	0.87	0.59	0.76	2,525
Fri	29/04/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 1	**Spring**		**28:07**	**32.47**	**36.88**	**26.90**	**0.30**	**0.22**	**29.52**	**38.20**	**20.61**	**1.64**	**0.41**	**105.13**	**206.66**	**-57.12**	**124,145.99**	**8.04**	**1.15E-01**	**3.12E-01**	**7.33E-03**	**6.63E-07**	**9.86E-03**	**10.58**	**33.80**	**6.38**	**165.21**	**1.68**	**1.32**	**4.22**	**0.80**	**0.04**	**0.21**	**1,813**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	15/08/16	IW	8:05	33.09	34.39	30.13	0.30	0.55	30.27	33.21	26.86	0.57	0.76	101.10	122.90	30.12	162.52	12.75	2.56E-01	8.75E-01	6.59E-02	1.61E-02	1.27E-01	10.81	35.05	6.46	13.65	3.69	1.35	4.38	0.81	0.21	0.46	1,699
Tues	16/08/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wed	17/08/16		8:35	33.04	34.34	29.83	0.83	0.91	30.62	32.94	26.86	1.14	1.07	86.20	107.29	45.58	154.73	12.44	1.28E-01	4.19E-01	1.25E-02	4.91E-03	7.01E-02	10.23	26.87	6.80	8.84	2.97	1.28	3.36	0.85	0.14	0.37	1,554
Thurs	18/08/16		7:51	33.48	34.87	28.64	0.89	0.95	30.83	33.35	25.85	1.05	1.02	95.22	133.39	53.92	157.28	12.54	3.05E-01	6.90E-01	2.05E-02	2.51E-02	1.59E-01	10.55	31.50	6.46	15.62	3.95	1.32	3.94	0.81	0.24	0.49	2,451
Fri	19/08/16		7:10	32.41	33.10	28.72	0.30	0.55	30.03	30.82	26.12	0.39	0.63	84.92	131.20	69.91	72.85	8.54	2.67E-01	4.54E-01	3.66E-02	1.40E-02	1.18E-01	10.98	32.18	7.00	19.59	4.43	1.37	4.02	0.87	0.31	0.55	2,127
Week 2	**Summer**		**31:41**	**33.01**	**34.87**	**28.64**	**0.08**	**0.19**	**30.44**	**33.35**	**25.85**	**0.10**	**0.18**	**88.78**	**133.39**	**30.12**	**1,372.94**	**1.75**	**2.39E-01**	**8.75E-01**	**1.25E-02**	**5.17E-05**	**3.17E-02**	**10.65**	**35.05**	**6.46**	**14.98**	**0.53**	**1.33**	**4.38**	**0.81**	**0.00**	**0.07**	**1,958**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	14/09/15	IW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tues	15/09/15		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Wed	16/09/15		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thurs	17/09/15		9:23	31.64	33.82	26.22	1.14	1.07	28.14	30.23	20.42	1.32	1.15	123.94	188.43	98.30	211.24	14.53	2.50E-01	8.40E-01	2.05E-02	9.92E-03	9.96E-02	11.54	33.52	6.46	27.58	5.25	1.44	4.19	0.81	0.43	0.66	4,550
Fri	18/09/15		7:46	31.87	32.88	26.22	0.56	0.75	28.77	29.87	20.42	0.95	0.97	110.25	188.43	95.09	116.62	10.80	1.49E-01	4.89E-01	2.05E-02	2.76E-03	5.25E-02	10.27	27.58	6.68	6.76	2.60	1.28	3.45	0.84	0.11	0.32	1,409
Week 3	**Autumn**		**17:09**	**31.75**	**33.82**	**26.22**	**0.08**	**0.16**	**28.46**	**30.23**	**20.42**	**0.03**	**0.09**	**117.10**	**188.43**	**95.09**	**2,238.24**	**1.87**	**1.99E-01**	**8.40E-01**	**2.05E-02**	**1.28E-05**	**2.36E-02**	**10.91**	**33.52**	**6.46**	**108.30**	**1.33**	**1.36**	**4.19**	**0.81**	**0.03**	**0.17**	**2,980**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	05/12/16	IW	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Tues	06/12/16		8:28	31.93	32.97	30.08	0.21	0.46	28.95	30.06	26.20	0.30	0.54	106.08	196.79	79.89	190.00	13.78	1.14E-01	1.58E-01	8.06E-03	7.02E-04	2.65E-02	10.64	33.45	6.89	17.86	4.23	1.33	4.18	0.86	0.28	0.53	3,002
Wed	07/12/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Thurs	08/12/16		6:59	32.40	33.23	28.51	0.60	0.77	29.66	30.71	23.99	0.89	0.95	97.83	165.05	77.82	120.12	10.96	1.56E-01	3.24E-01	1.10E-02	3.79E-03	6.16E-02	10.50	32.50	6.78	20.84	4.57	1.31	4.06	0.85	0.33	0.57	1,813
Fri	09/12/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	**Winter**		**15:27**	**32.17**	**33.23**	**28.51**	**0.04**	**0.16**	**29.30**	**30.71**	**23.99**	**0.09**	**0.20**	**101.95**	**196.79**	**77.82**	**1,220.92**	**1.41**	**1.35E-01**	**3.24E-01**	**8.06E-03**	**2.39E-06**	**1.75E-02**	**10.57**	**33.45**	**6.78**	**2.22**	**0.17**	**1.32**	**4.18**	**0.85**	**0.00**	**0.02**	**2,408**
Weekly (Seasonal) Average Summary (x4 wks)			**BSRIA (IW)**	**32.48**	**34.04**	**28.51**			**29.61**	**31.93**	**24.30**			**102.56**	**162.54**	**61.62**			**1.74E-01**	**4.29E-01**	**1.98E-02**			**10.65**	**30.51**	**6.68**			**1.33**	**3.81**	**0.84**			**2,289**

Seasonal Weekly % Average difference																								
Week 1	*Spring*	**BSRIA (IW)**	-0.02%	8.32%	-5.64%		-0.31%	19.64%	-15.19%		2.51%	27.15%	-192.70%		-33.86%	-27.27%	-63.08%		-0.69%	10.79%	-4.56%		-0.69%	10.79%	-4.56%		-20.82%
Week 2	*Summer*		1.62%	2.42%	0.45%		2.78%	4.44%	6.40%		-13.43%	-17.93%	-51.12%		37.53%	103.74%	-37.23%		-0.09%	14.89%	-3.27%		-0.09%	14.89%	-3.27%		-14.49%
Week 3	*Autumn*		-2.23%	-0.66%	-8.03%		-3.90%	-5.31%	-15.93%		14.18%	15.93%	54.31%		14.81%	95.69%	3.38%		2.36%	9.85%	-3.27%		2.36%	9.85%	-3.27%		30.14%
Week 4	*Winter*		-0.96%	-2.37%	0.01%		-1.04%	-3.82%	-1.25%		-0.59%	21.07%	26.29%		-22.13%	-24.53%	-59.39%		-0.80%	9.64%	1.38%		-0.80%	9.64%	1.38%		5.16%

Abbreviations

Avge ***Average mean value of all arguments***
Max ***Maximum value within data set***
Min ***Minimum value within data set***
Var ***Variance from the average mean across the data set***
SD ***Standard Deviation from the average mean value across all data sets***
N/A ***Volunteer Not Available***

Table 52 - Sensewear Armband Measured Values – Volunteer (IW)

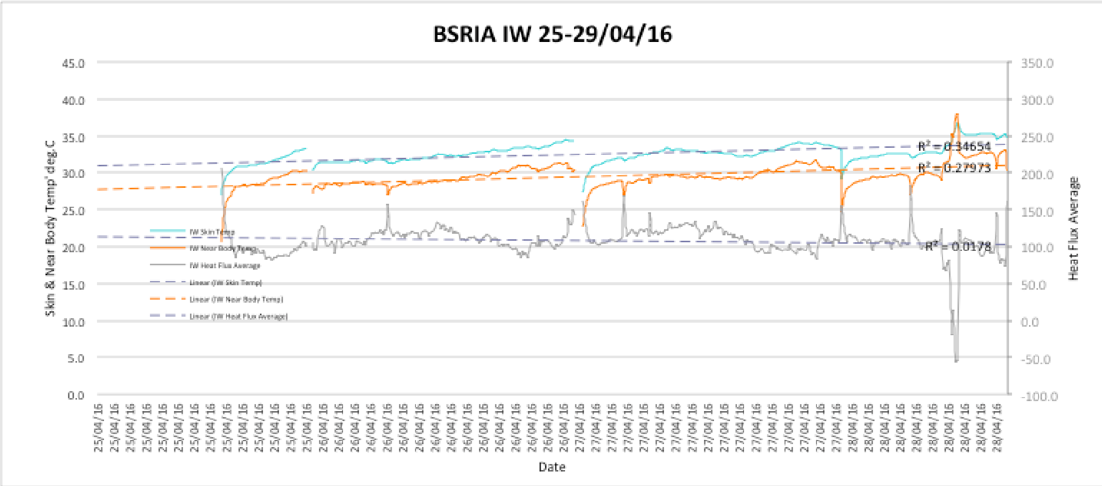


Fig .128 – IW Seasonal Skin & Near Body Temperature and Heat Flux – April 2016 (Spring)

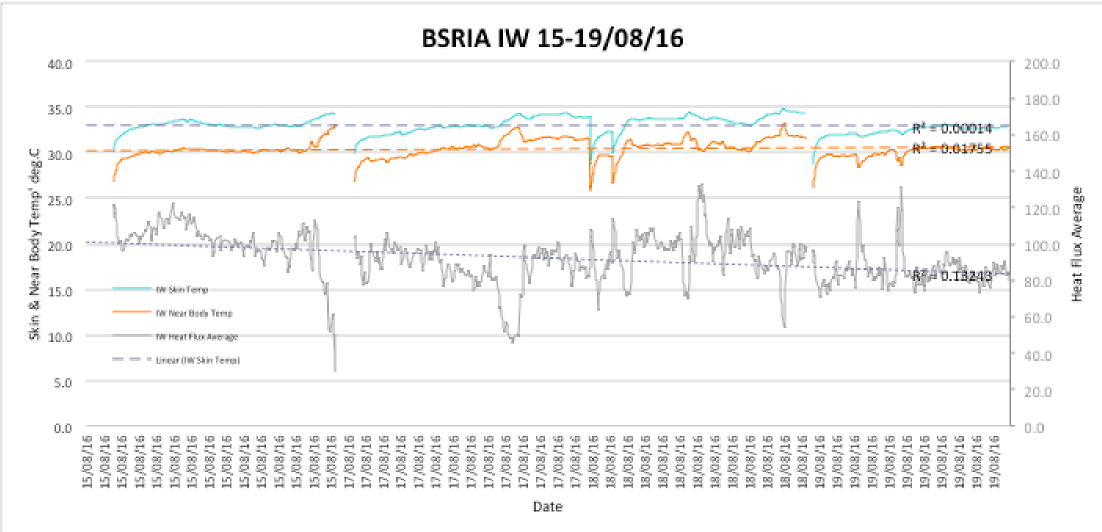


Fig.129 – IW Seasonal Skin & Near Body Temperature and Heat Flux – August 2016 (Summer)

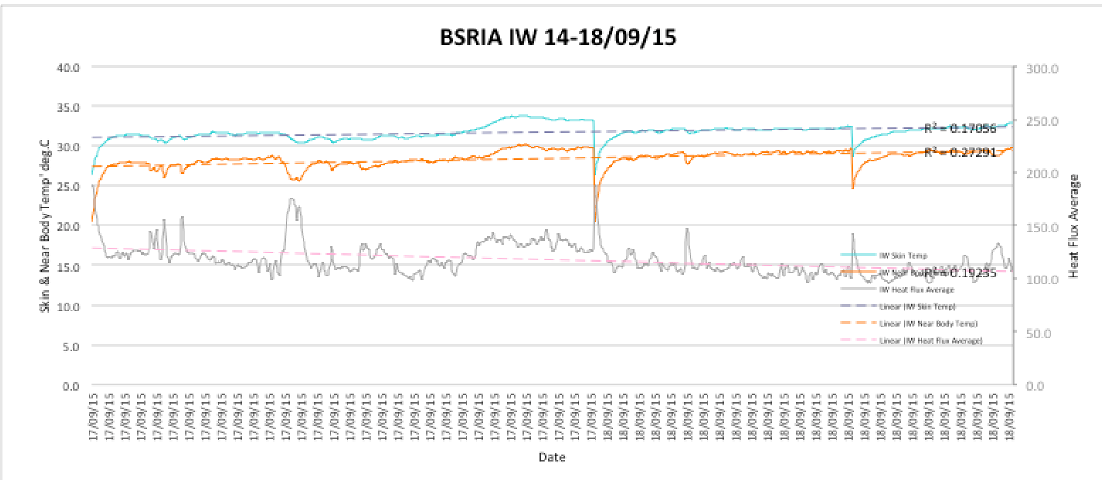


Fig.130 – IW Seasonal Skin & Near Body Temperature and Heat Flux – September 2015 (Autumn)

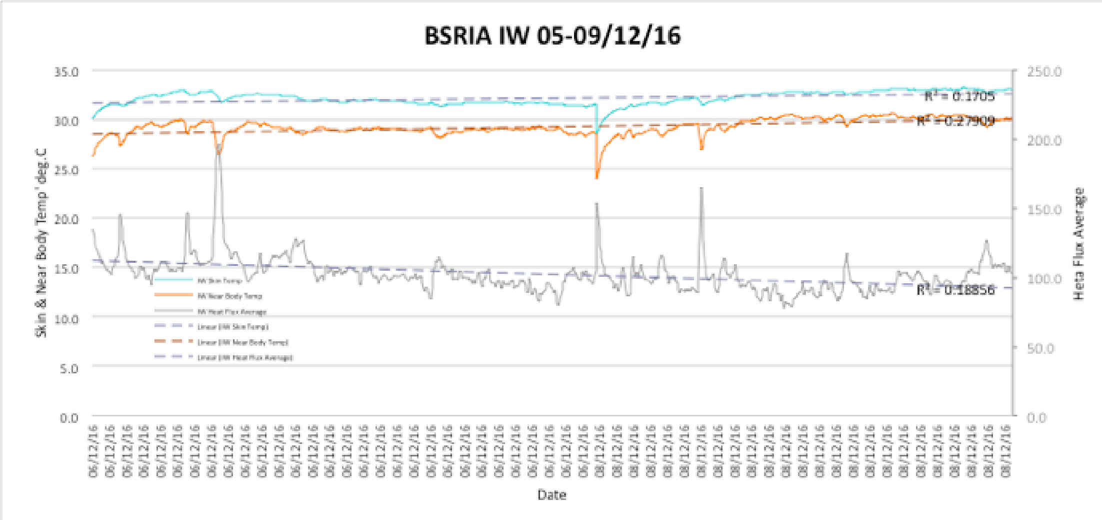


Fig. 131 – IW Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Fig's 128-131represent the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 53. As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier. Similar results were found with volunteer (MA-H)

Heat Flux average is a more variable set of values with greater R^2 values but with relatively low inclination of the trend line. All seasons demonstrate a downward trend over each season. Volunteer (IW) values indicate a very consistent set of values with excellent relationships to thermal skin and near body events.

The following Fig's. 132-135 represents a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

Fig. 132 – IW Daily Skin & Near Body Temperature and Heat Flux Values April 2016 (Spring)

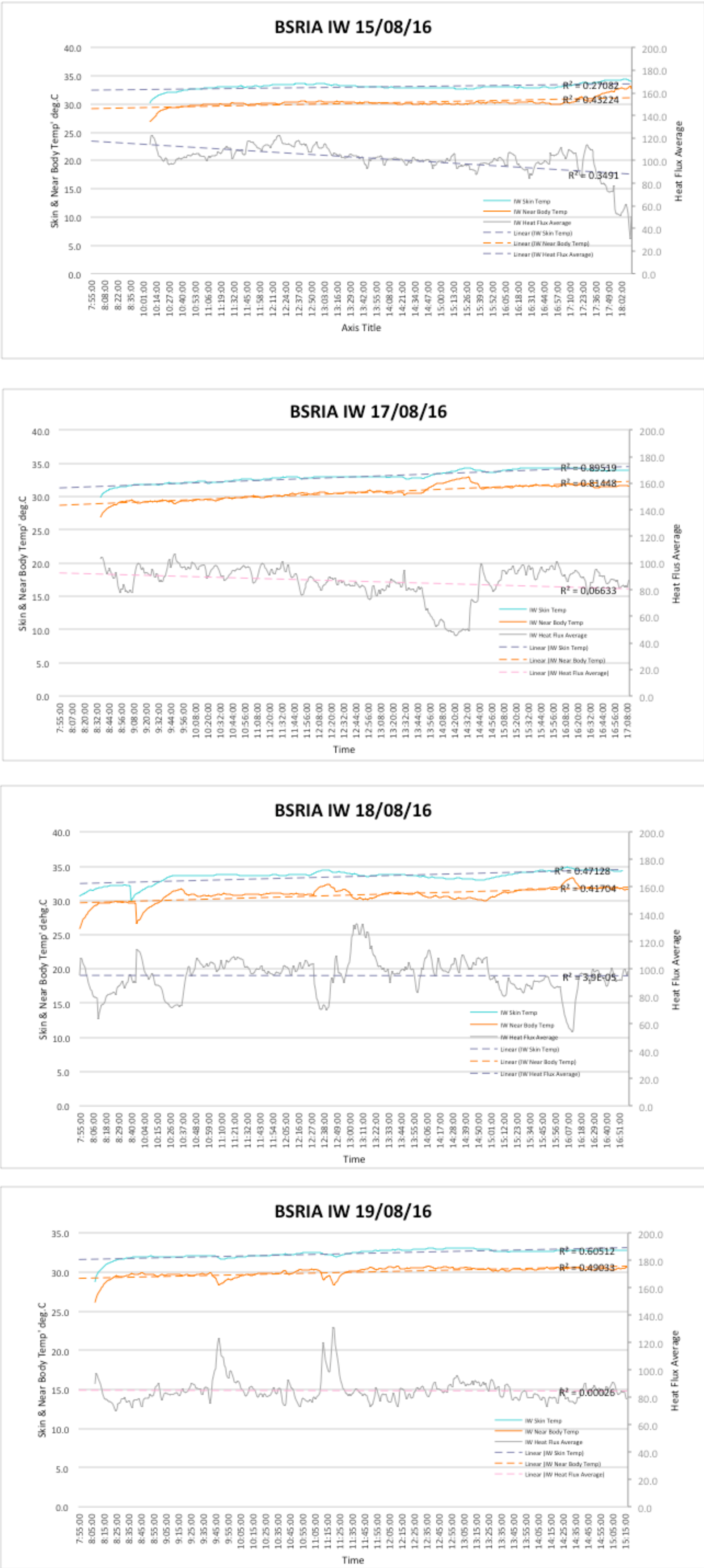
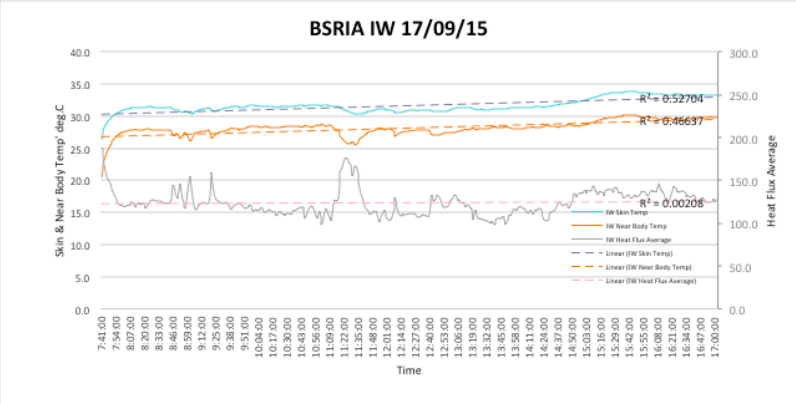


Fig. 133 – IW Daily Skin & Near Body Temperature and Heat Flux Values August 2016 (Summer)



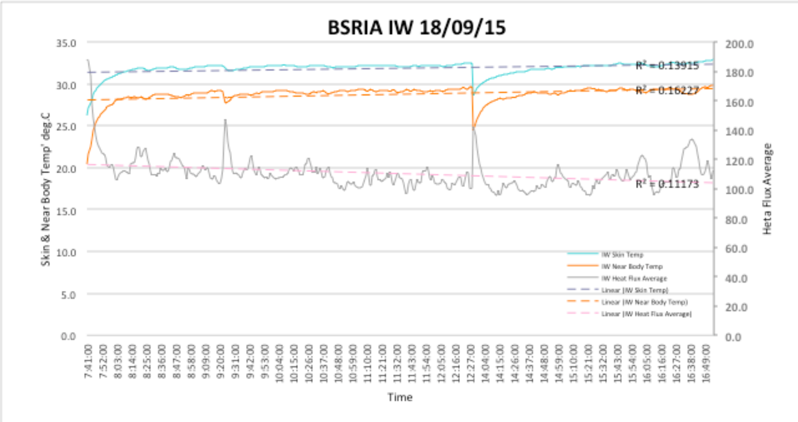
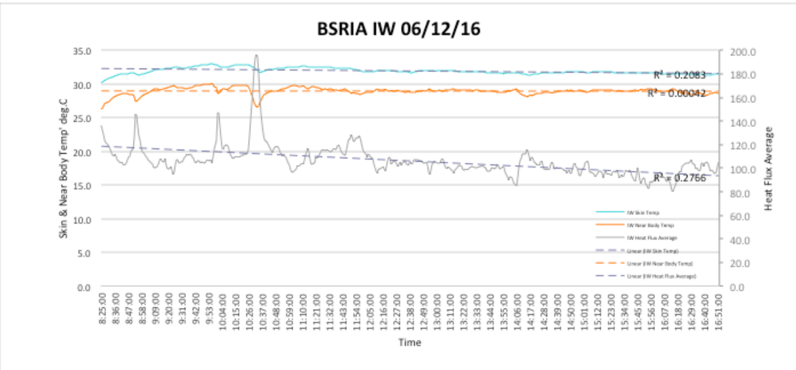


Fig. 134 – IW Daily Skin & Near Body Temperature and Heat Flux Values September 2016 (Autumn)



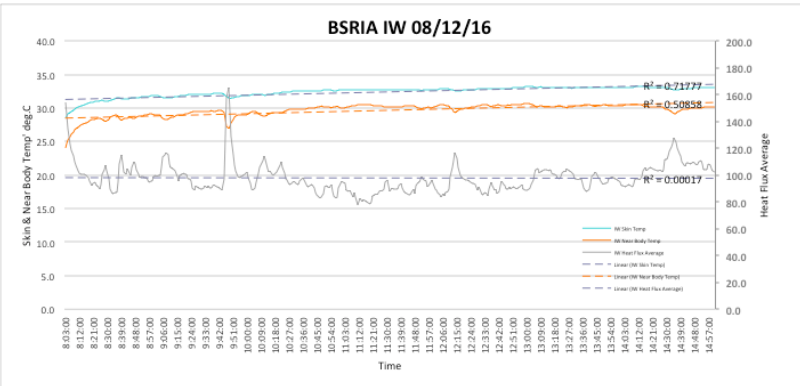


Fig 135 – IW Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

Within each of Fig's. 132-135 the Skin and Near Body temperature rises continually throughout the day as seen across other volunteers and within normal expected physical body temperature expectations. Heat flux average trends consistently downward at varying degrees of R^2 for all seasons. A sharp reduction or increase skin or near body temperature drives an opposite response from heat flux average value which is to be expected as a significant exchange in thermal exchange is experienced. This is consistent with Volunteer (MA-H).

Fig's. 136-139 represents Galvanic Skin Response and indicate the equivalent periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead. Spring, summer and winter weekly trends indicate an upward trend line.

Fig.136 for the spring period indicates a constant increase in GSR value overall during the day with a number sharp decreases creating a saw tooth trace on the 26/04/16. This was assessed as the user making the armband more comfortable and interrupting the recording. The daily GSR response continues each day with significant sharp increases in GSR value along each graph.

Fig.137 summer provides traces for 4-days with similar profiles being noted. The continually daily increase with sharp interspersed increases suggests time dependant interventions primarily business related during the day. The period for Monday displays a significant increase in GSR values around lunchtime and late afternoon assessed as lunch and business related issues..

Fig. 138 autumn provides only two daily traces recording a downward trend for the only seasonal period. The lunchtime and afternoon periods again display sharp increases in GSR value.

Fig. 139 winter indicates an upward trend with a continuous daily increase interspersed with sharp increases in GSR value values throughout the Tues period. Time dependant events can seen clearly in the lunchtime and afternoon periods across each seasonal period, however the profiles differ significantly.

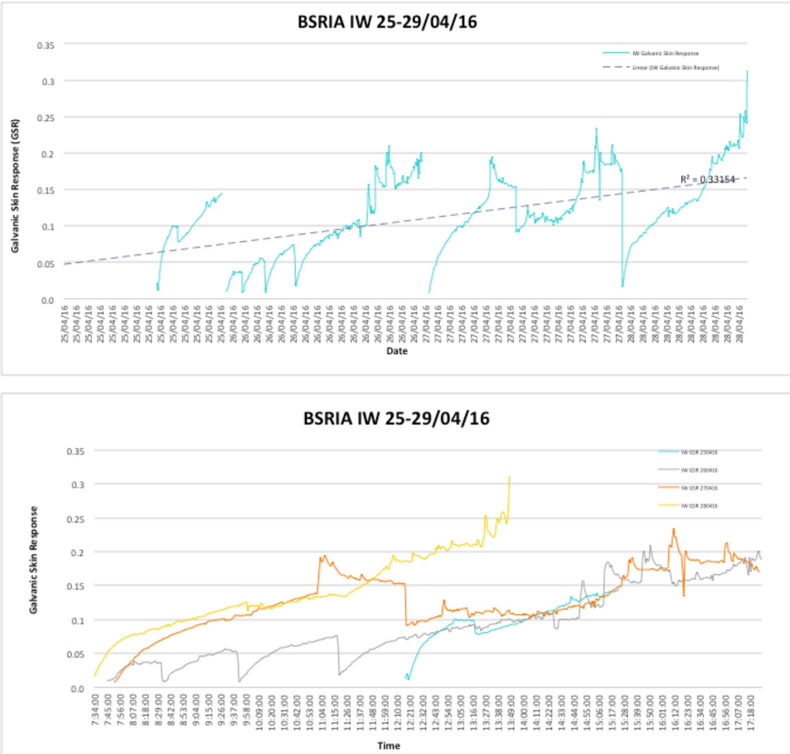


Fig. 136 – IW GSR Daily and Weekly Measured Values April 2016 (Spring)

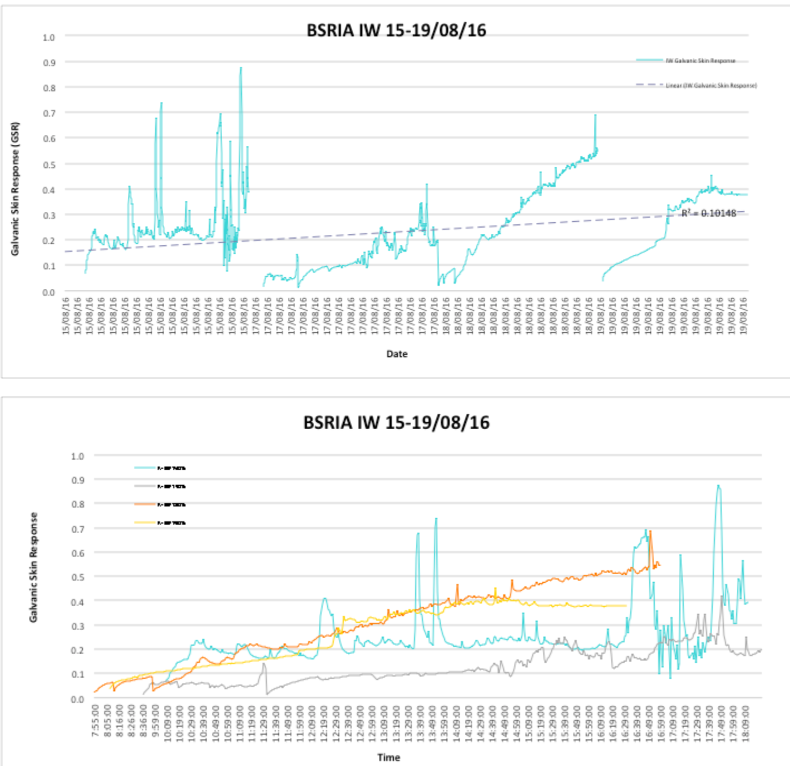


Fig. 137 – IW GSR Daily and Weekly Measured Values August 2016 (Summer)

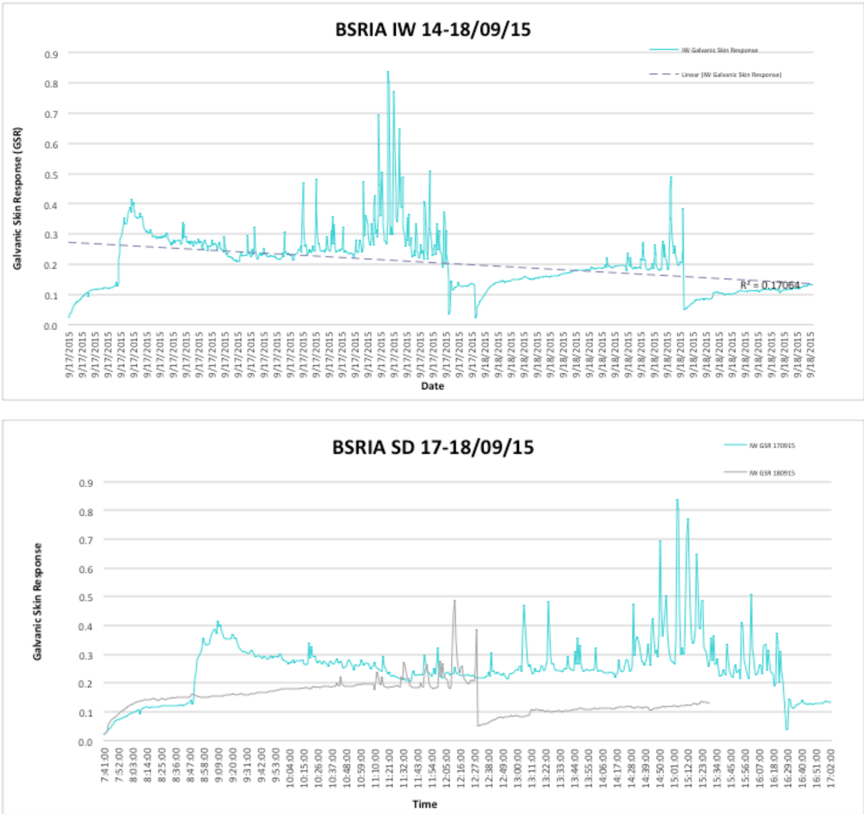


Fig. 138 – IW GSR Daily and Weekly Measured Values September 2015 (Autumn)

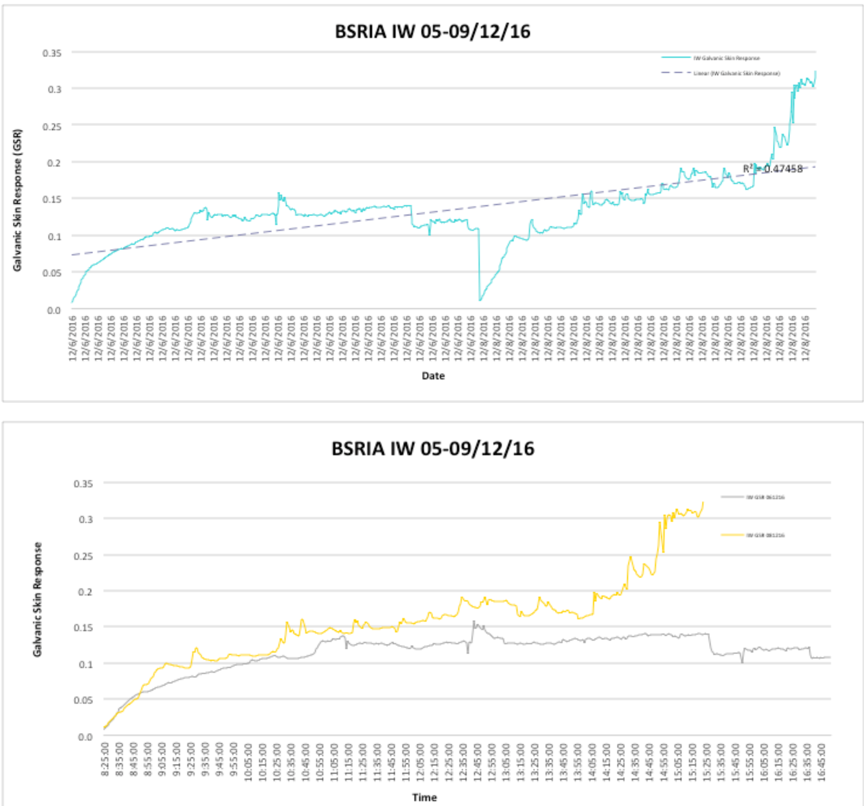


Fig. 139 – IW GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.7 BSRIA Volunteer 1 (SD)

Table 53 indicates the measured data obtained from volunteer (MA-H). A smoking female of weight 72.6kg height 165.1cm and BMI of 26.6. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent. Volunteer (SD) was a consistent and excellent participant with a total armband on body time of 129hrs 31mins (81%) from an expected research time of 160 hrs (8hrs/day x5-days/wk x4 seasonal periods). The volunteer was not available for 2-days 19/08/16 and 09/12/16. The data is considered sufficient for analysis.

The average skin temperature noted within Table 53 across spring, summer and autumn would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. Variance and standard deviation are small supporting the possibility that both parameters would be suitable for building system feedback acceptance. The Weekly (Seasonal) Average Skin Temperature of 32.38 deg.C applied to each seasonal weekly average value indicates a 1.93% increase during Spring; 0.01% increase during Summer; 0.50% increase during Autumn; and -3.04% decrease during Winter. Across all x4 seasons Maximum values range -3.24% during winter to 10.79% during summer with Minimum values ranging between -26.07% during winter to 0.04% during spring.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 29.40 deg.C applied to each seasonal weekly average value indicates a 1.38% increase during Spring; 0.06% increase during Summer; 0.80% increase during Autumn; and -2.80% decrease during Winter. Across all x4 seasons Maximum figures range -1.19% during winter to 28.23% during summer with Minimum figures ranging between -17.79% during winter to 0.95% during summer.

Heat flux average values although relatively consistent overall between the seasons the graphical representation would propose that this physiological measurement is not sufficiently accurate to use within any potential feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 105.96 W/m^2 applied to each seasonal weekly average value indicates a 4.81% increase during Spring; 1.97% increase during Summer; -2.11% decrease during Autumn; and -5.80% decrease during Winter. Across all x4 seasons Maximum figures range 33.94% spring to 1.22% during summer with Minimum figures ranging between -335.83% summer to 10.05% during autumn.

Galvanic skin response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (µS) of 7.66E-02 applied to each seasonal weekly average value indicates a 7.33% increase during Spring; 7.68% increase during Summer; -13.97% decrease during Autumn; and 0.57% increase during Winter. Across all x4 seasons Maximum figures range 96.81% during spring to 21.45 during summer with Minimum figures ranging between -63.43% during spring to -50.13% during summer.

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 6.92 (KJ) applied to each seasonal weekly average value indicates a -03.71% decrease during Spring; 4.50% increase during Summer; 3.04% increase during Autumn; and -3.66% decrease during Winter. Across all x4 season's Maximum figures range 39.31% during spring to -3.78% during summer with Minimum values ranging between -0.08% during spring/summer to -10.81% during winter. The Weekly (Seasonal) Average Metabolic Equivalent value 1.44 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -8.78% decrease during Spring; -1.01% decrease during Summer; -2.39% decrease during Autumn; and 14.97% increase during winter. Across all x4 season's Maximum figures range -9.34% during summer to 37.23% during winter with Minimum figures ranging between -8.10% during autumn to 6.73% during winter. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteer - SD

BSRIA - Bracknell - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)				
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	25/04/16		4:18	33.56	34.48	27.88	1.30	1.14	29.44	31.86	22.19	2.15	1.47	108.51	191.03	89.95	178.02	13.34
Tues	26/04/16		8:41	32.31	33.84	28.81	0.78	0.88	29.49	29.49	29.49	0.00	0.00	121.31	219.12	55.37	380.43	19.50
Wed	27/04/16		3:34	33.46	33.86	29.21	0.39	0.62	30.53	31.36	22.58	1.38	1.17	104.98	226.13	79.15	392.22	19.80
Thurs	28/04/16	SD	7:40	32.34	33.35	28.55	0.63	0.80	29.10	30.75	23.04	1.13	1.06	115.75	189.50	92.94	184.96	13.60
Fri	29/04/16		7:47	33.39	34.68	28.07	0.67	0.82	30.47	32.06	22.72	1.27	1.13	104.73	180.75	86.04	217.26	14.74
Week 1	**Spring**		**32:00**	**33.01**	**34.68**	**27.88**	**0.09**	**0.17**	**29.81**	**32.06**	**22.19**	**0.48**	**0.50**	**111.06**	**226.13**	**55.37**	**9,121.23**	**2.86**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	15/08/16		6:16	33.06	35.05	29.32	1.14	1.07	29.61	29.61	29.61	0.00	0.00	112.50	160.51	30.56	431.83	20.78
Tues	16/08/16		8:16	32.27	34.50	27.40	1.98	1.41	29.22	34.66	24.32	2.75	1.66	108.53	168.68	-13.36	566.12	23.79
Wed	17/08/16		8:23	33.14	37.55	28.45	1.58	1.26	30.21	40.47	24.91	5.00	2.24	104.62	170.89	-135.50	2,622.60	51.21
Thurs	18/08/16	SD	4:02	31.75	32.63	29.44	0.27	0.52	28.62	29.74	26.01	0.58	0.76	111.00	170.55	82.22	227.78	15.09
Fri	19/08/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 2	**Summer**		**26:57**	**32.39**	**37.55**	**27.40**	**0.40**	**0.34**	**29.42**	**40.47**	**24.32**	**3.90**	**0.85**	**108.05**	**170.89**	**-135.50**	**933,623.88**	**13.92**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	14/09/15		8:26	31.12	33.10	27.65	0.57	0.76	28.12	30.45	23.12	1.00	1.00	105.83	154.71	58.29	354.11	18.82
Tues	15/09/15		8:14	33.44	34.96	27.86	1.08	1.04	30.72	32.35	23.77	1.30	1.14	97.65	142.74	73.80	242.36	15.57
Wed	16/09/15		8:38	32.08	33.48	28.96	0.70	0.84	29.26	31.42	24.22	1.45	1.21	100.17	162.81	60.11	439.55	20.97
Thurs	17/09/15	SD	6:37	32.40	34.59	26.92	1.53	1.24	29.09	32.30	21.89	2.95	1.72	118.04	174.25	78.65	635.47	25.21
Fri	18/09/15		7:55	33.68	34.34	28.11	0.61	0.78	30.98	31.91	23.73	0.99	1.00	96.92	148.96	77.48	135.29	11.63
Week 3	**Autumn**		**39:50**	**32.55**	**34.96**	**26.92**	**0.13**	**0.18**	**29.63**	**32.35**	**21.89**	**0.53**	**0.27**	**103.72**	**174.25**	**58.29**	**29,314.91**	**4.62**
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	05/12/16		7:44	31.49	32.79	26.70	0.97	0.98	28.29	29.59	21.35	1.64	1.28	113.15	176.17	89.00	210.94	14.52
Tues	06/12/16		8:30	31.08	32.21	30.04	0.20	0.45	28.35	29.49	26.70	0.27	0.52	96.47	130.70	59.61	210.32	14.50
Wed	07/12/16		8:17	31.89	32.74	20.61	0.95	0.97	29.39	31.18	19.80	1.16	1.08	88.91	135.98	20.50	292.74	17.11
Thurs	08/12/16	SD	6:13	31.13	31.82	27.69	0.26	0.51	28.28	29.38	24.13	0.57	0.76	100.73	135.49	68.58	151.96	12.33
Fri	09/12/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	**Winter**		**30:44**	**31.40**	**32.79**	**20.61**	**0.13**	**0.25**	**28.58**	**31.18**	**19.80**	**0.28**	**0.29**	**99.82**	**176.17**	**20.50**	**2,511.69**	**1.69**
Weekly (Seasonal) Average Summary (x4 wks)			**BSRIA (SD)**	**32.38**	**33.89**	**27.87**			**29.40**	**31.56**	**24.09**			**105.96**	**168.83**	**52.97**		

Day	Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	1.05E-01	1.92E-01	1.76E-02	7.54E-04	2.75E-02	6.60	18.93	4.46	8.12	2.85	1.30	3.74	0.88	0.32	0.56	1,226
Tues	8.64E-02	1.08E-01	1.17E-02	8.59E-05	9.27E-03	7.15	28.54	4.36	12.02	3.47	1.41	5.64	0.86	0.47	0.69	2,896
Wed	6.53E-02	8.65E-02	2.93E-02	8.47E-05	9.20E-03	6.01	17.48	4.47	4.04	2.01	1.19	3.45	0.88	0.16	0.40	607
Thurs	6.78E-02	1.02E-01	8.06E-03	3.55E-04	1.88E-02	6.66	20.53	4.31	6.52	2.55	1.32	4.06	0.85	0.25	0.50	2,089
Fri	8.66E-02	1.80E-01	3.22E-02	5.75E-04	2.40E-02	6.90	21.15	4.23	9.33	3.05	1.36	4.18	0.84	0.36	0.60	2,627
Week 1	**8.23E-02**	**1.92E-01**	**8.06E-03**	**7.03E-08**	**7.47E-03**	**6.66**	**28.54**	**4.23**	**7.17**	**0.49**	**1.32**	**5.64**	**0.84**	**0.01**	**0.10**	**1,889**
Analysis 2	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	1.02E-01	1.71E-01	1.10E-02	2.80E-04	1.67E-02	6.81	18.86	4.23	7.13	2.67	1.35	3.73	0.84	0.28	0.53	1,698
Tues	9.02E-02	1.59E-01	2.12E-02	1.50E-04	1.22E-02	7.17	19.72	4.28	11.82	3.44	1.42	3.90	0.85	0.46	0.68	3,597
Wed	7.41E-02	1.89E-01	2.34E-02	8.22E-04	2.87E-02	6.84	19.08	4.37	6.85	2.62	1.35	3.77	0.86	0.27	0.52	2,508
Thurs	6.42E-02	1.62E-01	4.40E-02	3.65E-04	1.91E-02	8.11	18.96	4.32	10.83	3.29	1.60	3.75	0.85	0.42	0.65	1,950
Fri	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 2	**8.25E-02**	**1.89E-01**	**1.10E-02**	**6.40E-08**	**6.00E-03**	**7.23**	**19.72**	**4.23**	**4.83**	**0.36**	**1.43**	**3.90**	**0.84**	**0.01**	**0.07**	**2,438**
Analysis 3	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	7.58E-02	3.06E-01	8.79E-03	5.91E-04	2.43E-02	6.95	19.91	4.09	11.18	3.34	1.37	3.93	0.81	0.44	0.66	3,383
Tues	7.57E-02	9.23E-02	2.34E-02	7.84E-05	8.86E-03	6.79	19.46	4.46	7.30	2.70	1.34	3.84	0.88	0.29	0.53	2,901
Wed	5.52E-02	9.23E-02	9.52E-03	5.69E-05	7.55E-03	7.31	19.70	4.23	10.12	3.18	1.44	3.89	0.84	0.40	0.63	3,289
Thurs	6.21E-02	2.79E-01	1.17E-02	7.35E-04	2.71E-02	7.65	19.58	4.39	9.49	3.08	1.51	3.87	0.87	0.37	0.61	3,334
Fri	6.07E-02	1.06E-01	2.93E-02	1.34E-04	1.16E-02	6.96	19.83	4.49	9.28	3.05	1.37	3.92	0.89	0.36	0.60	3,382
Week 3	**6.59E-02**	**3.06E-01**	**8.79E-03**	**8.17E-08**	**8.18E-03**	**7.13**	**19.91**	**4.09**	**1.62**	**0.21**	**1.41**	**3.93**	**0.81**	**0.00**	**0.04**	**3,258**
Analysis 4	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	6.72E-02	1.03E-01	1.90E-02	2.24E-04	1.50E-02	6.55	22.41	3.95	10.90	3.30	1.63	5.58	0.98	0.68	0.82	3,682
Tues	5.89E-02	1.14E-01	5.89E-02	1.65E-04	1.28E-02	6.86	23.69	3.77	14.01	3.74	1.71	5.90	0.94	0.87	0.93	5,754
Wed	9.61E-02	1.14E-01	9.52E-03	2.23E-04	1.49E-02	6.11	19.30	3.85	9.62	3.10	1.52	4.80	0.96	0.60	0.77	3,291
Thurs	8.60E-02	2.46E-01	2.78E-02	9.22E-04	3.04E-02	7.14	21.70	3.90	14.66	3.83	1.78	5.40	0.97	0.91	0.95	4,009
Fri	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	**7.71E-02**	**2.46E-01**	**9.52E-03**	**9.71E-08**	**7.03E-03**	**6.67**	**23.69**	**3.77**	**4.41**	**0.30**	**1.66**	**5.90**	**0.94**	**0.02**	**0.08**	**4,184**
Weekly (Seasonal) Average Summary (x4 wks)	**7.66E-02**	**1.56E-01**	**2.20E-02**			**6.92**	**20.49**	**4.23**			**1.44**	**4.30**	**0.88**			**2,942**

Seasonal Weekly % Average difference																						
Week 1	*Spring*	**BSRIA (SD)**	1.93%	2.35%	0.04%	1.38%	1.58%	-7.87%	4.81%	33.94%	4.54%	7.37%	23.33%	-63.43%	-3.71%	39.31%	-0.08%	-8.78%	31.26%	-5.09%	-35.80%
Week 2	*Summer*		0.01%	10.79%	-1.68%	0.06%	28.23%	0.95%	1.97%	1.22%	-355.83%	7.68%	21.45%	-50.13%	4.50%	-3.78%	-0.08%	-1.01%	-9.34%	-5.09%	-17.13%
Week 3	*Autumn*		0.50%	3.16%	-3.40%	0.80%	2.49%	-9.12%	-2.11%	3.21%	10.05%	-13.97%	96.81%	-60.10%	3.04%	-2.83%	-3.25%	-2.39%	-8.45%	-8.10%	10.72%
Week 4	*Winter*		-3.04%	-3.24%	-26.07%	-2.80%	-1.19%	-17.79%	-5.80%	4.35%	-61.30%	0.57%	57.71%	-56.78%	-3.66%	15.61%	-10.81%	14.97%	37.23%	6.73%	42.20%

Abbreviations

Avge ***Average mean value of all arguments***
Max ***Maximum value within data set***
Min ***Minimum value within data set***
Var ***Variance from the average mean across the data set***
SD ***Standard Deviation from the average mean value across all data sets***
N/A ***Volunteer Not Available***

Table 53 - Sensewear Armband Measured Values – Volunteer (SD)

Fig's. 140-143 represents the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 54 As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier.

Heat Flux average is a more variable set of values with greater R^2 values and significant inclination of the trend line. Spring and winter periods indicate a slight decreasing trend, however, the summer and autumn period indicate a more level trend. An analysis of ambient relationships is provided within Chapter 6.

Fig's. 144-147 represents a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

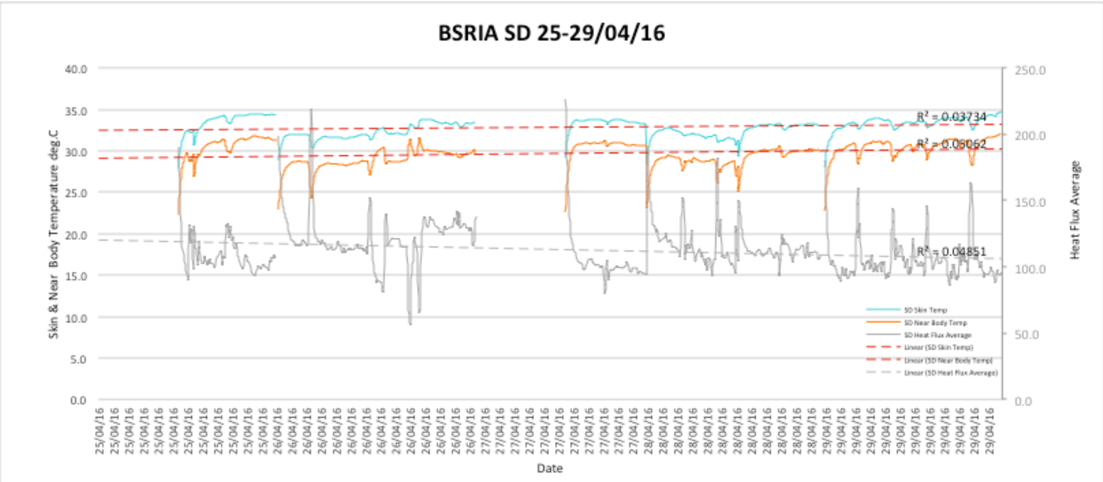


Fig. 140 – SD Seasonal Skin & Near Body Temperature and Heat Flux – April 2016 (Spring)

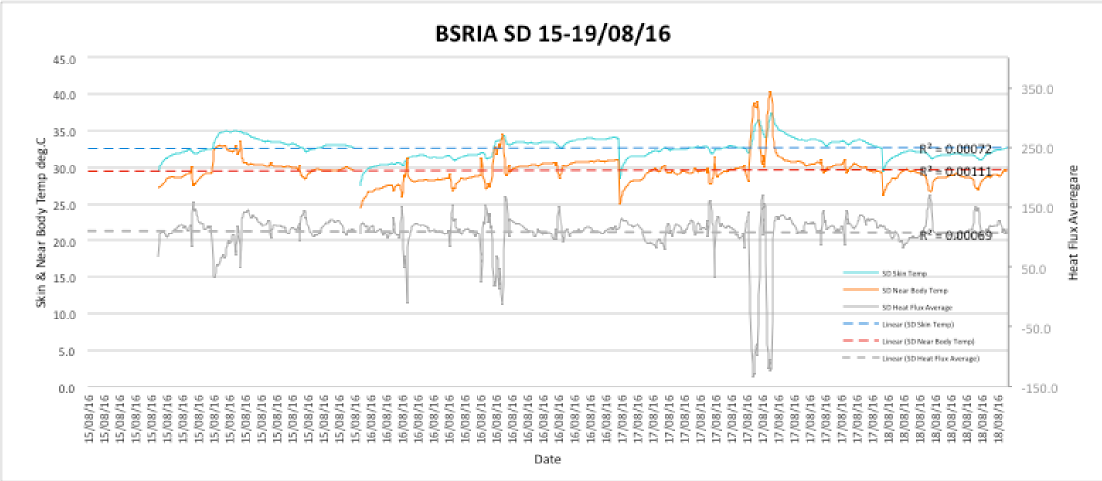


Fig. 141 – SD Seasonal Skin & Near Body Temperature and Heat Flux – August 2016 (Summer)

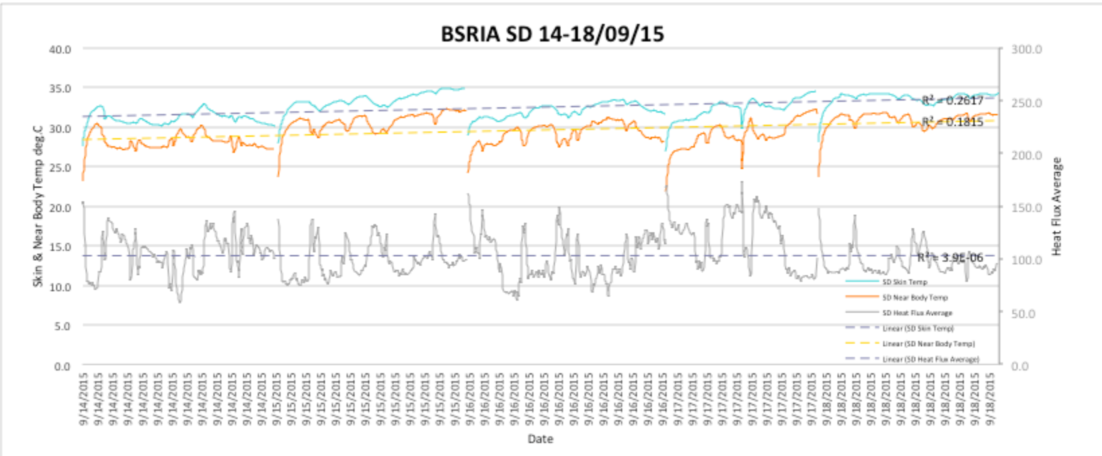


Fig. 142 – SD Seasonal Skin & Near Body Temperature and Heat Flux – September 2015 (Autumn)

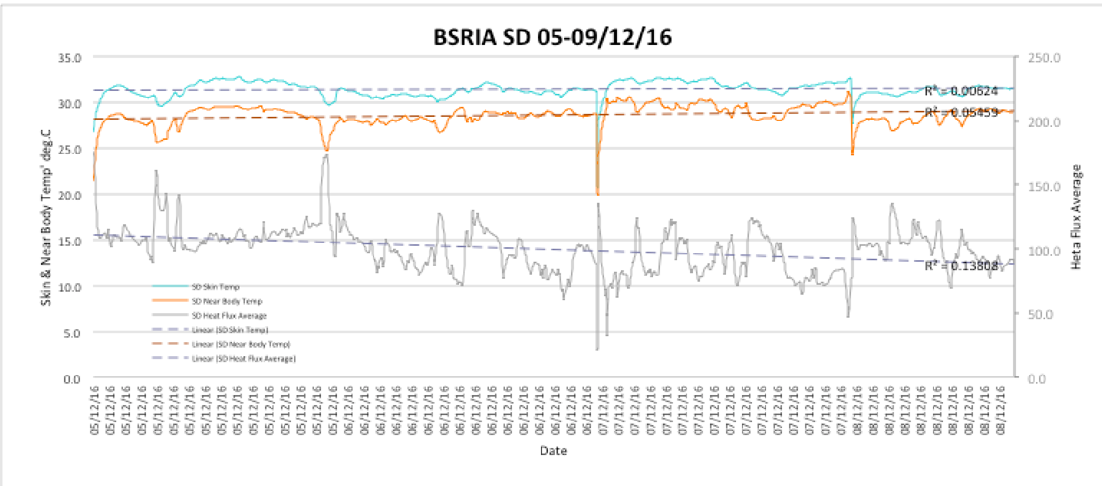


Fig. 143 – SD Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

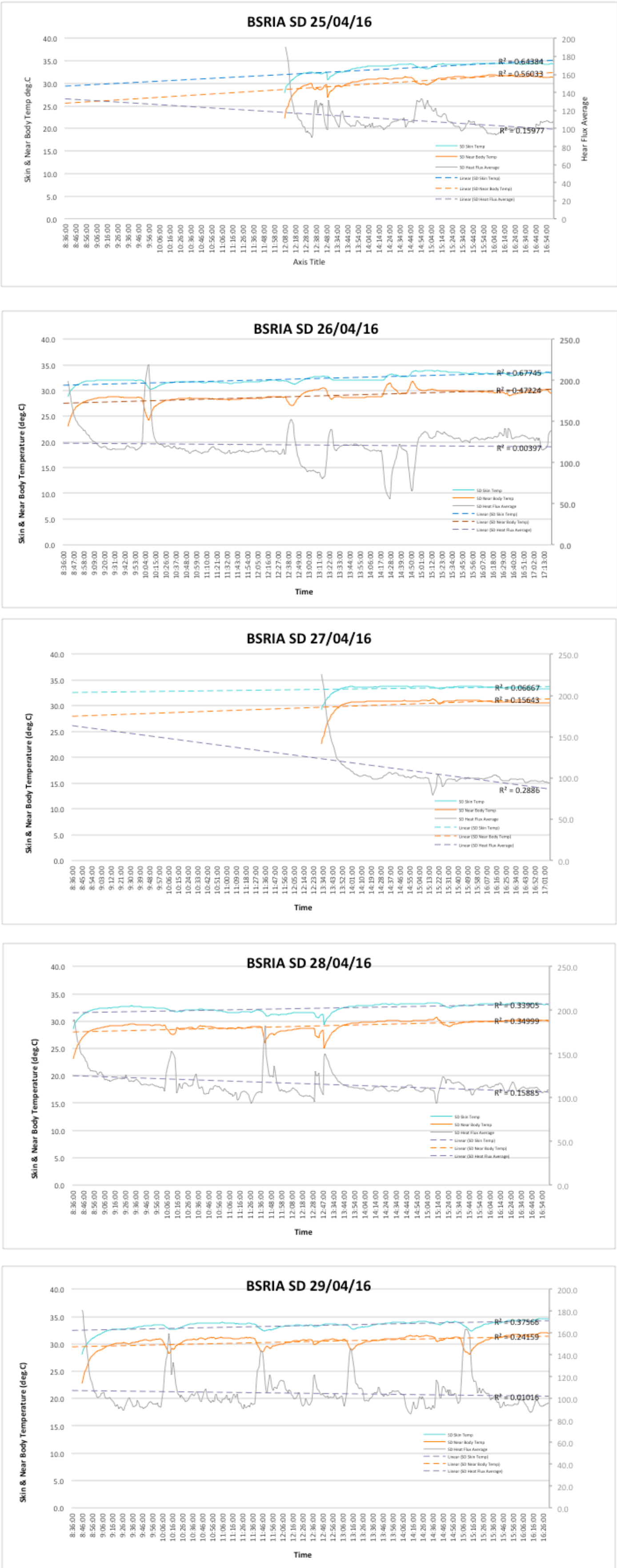
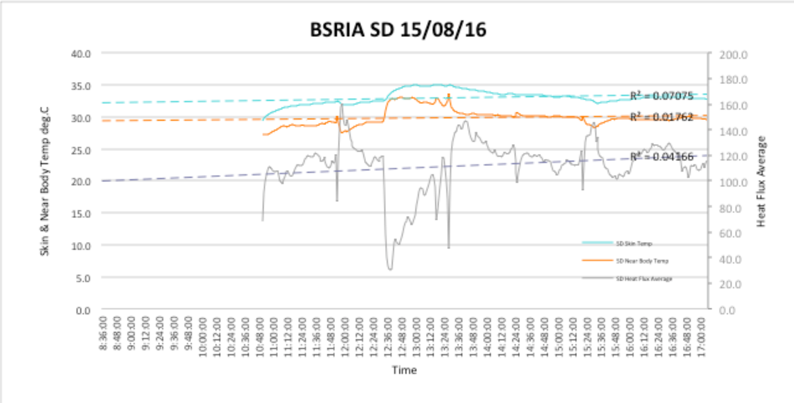
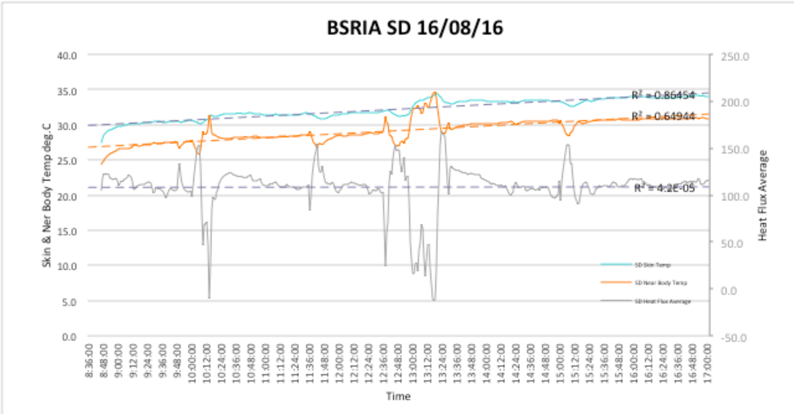
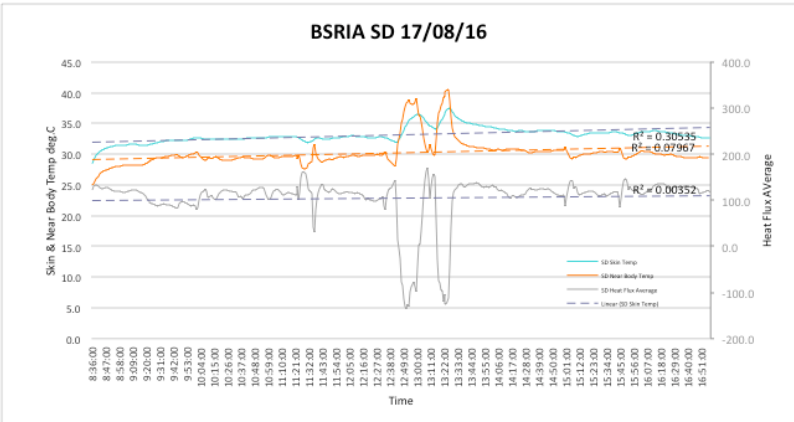


Fig. 144 – SD Daily Skin & Near Body Temperature and Heat Flux Values April 2016 (Spring)







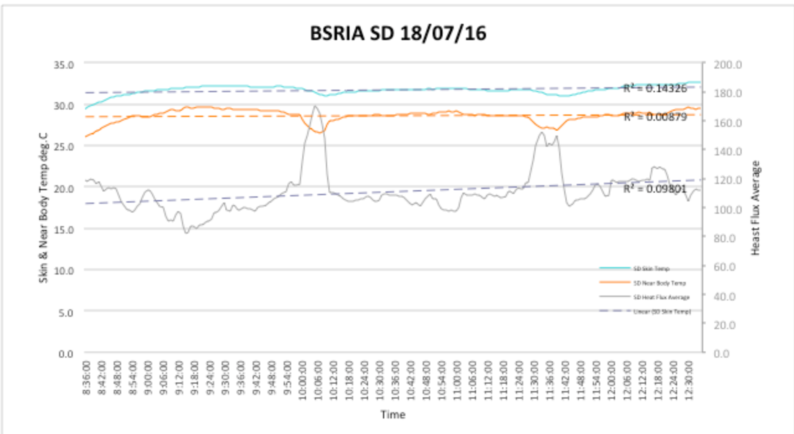


Fig. 145 – SD Daily Skin & Near Body Temperature and Heat Flux Values August 2016 (Summer)

Fig. 146 – SD Daily Skin & Near Body Temperature and Heat Flux Values September 2015 (Autumn)

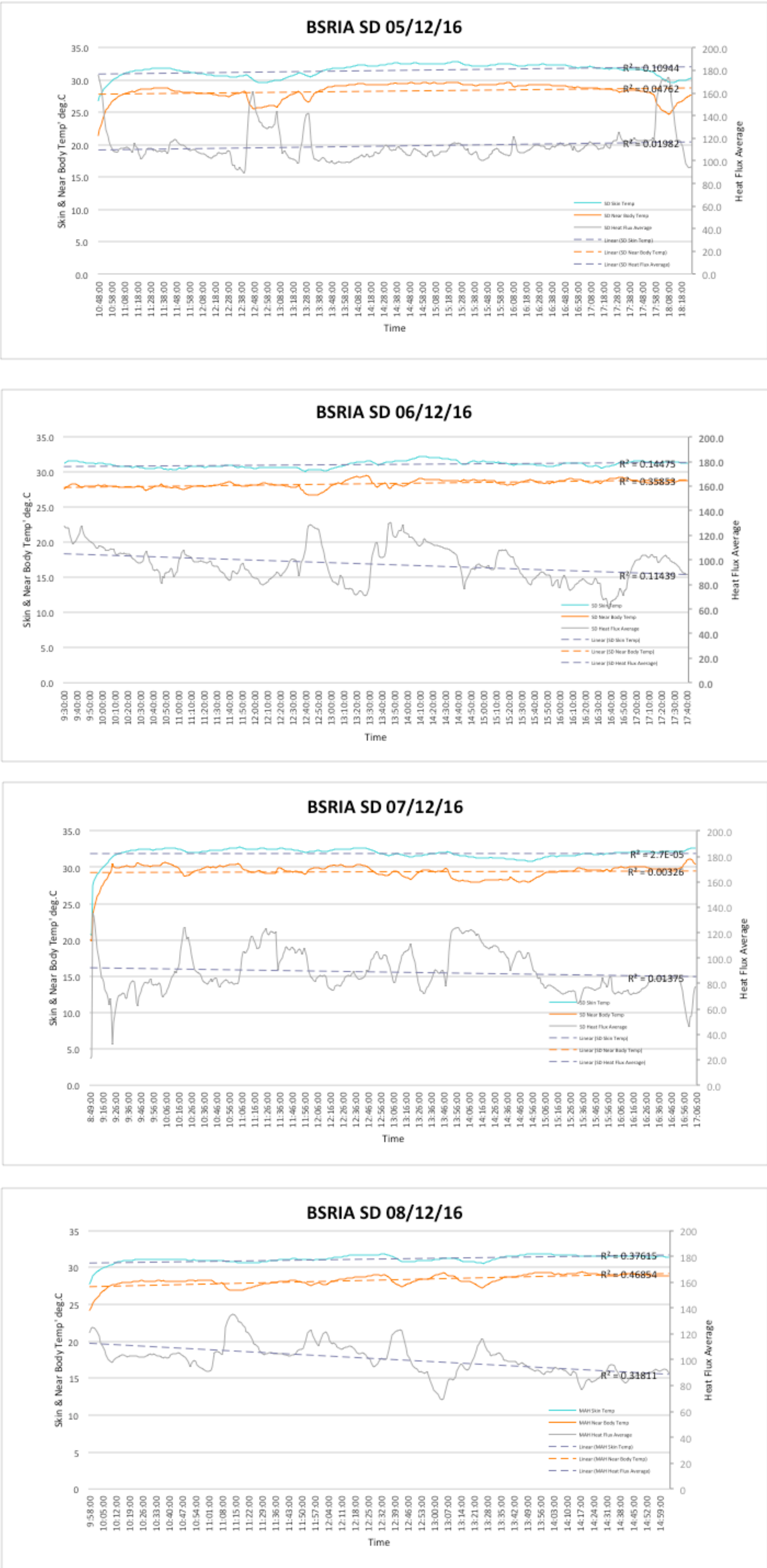


Fig. 147 – SD Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (Winter)

Within each of Fig’s 144-147 the Skin and Near Body temperature rises continually throughout the day as seen across other volunteers and within normal expected physical body temperature expectations. Heat flux average trend consistently downward at varying degrees of R^2 during spring, however during summer (2-days) Tues & Wed the trend line remains level while Mon & Thurs display an upward trend. During autumn Mon-Tues display an upward trend line while Thurs displays a downward trend, with Wed indicating a level trend line. A sharp reduction or increase skin or near body temperature drives an opposite response from heat flux average value which is to be expected as a significant exchange in thermal exchange is experienced. This is consistent with Volunteer (MA-H & IW). The winter period indicates a slight upward trend on Mon, with Tue-Thurs indicating a downward trend line.

Fig’s. 148-151 represents Galvanic Skin Response and indicate the equivalent periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead. Spring, summer and autumn weekly trends indicate an downward trend line, however winter indicates an upward trend line.

Fig 148 for the spring period displays a constant increase in GSR value overall during the day with a number sharp increases at lunchtime and in the afternoon. Following each sharp increase there is a period before returning to a lower level but in general not to the same GSR level. Tues, Thurs and Fri the morning period’s generally indicate typical values for the volunteer, however Monday consistently provides higher results across all volunteers. Wed is a midday start and indicates a typical profile within similar values and profile to other days. The afternoon periods appear to be more disruptive by the considerable sharp increases and decreases in GSR value.

Fig. 149 summer indicates similar daily profiles and a weekly downward trend Mon-Fri. with time dependant events noted at lunchtime early mornings. During afternoon periods there is considerable increases and decreases in GSR value consistent with the spring period.

Fig. 150 autumn indicates a different more rational set of values but still providing an overall weekly downward trend. The individual days however, do contain a number of very high increases in GSR value, with a number of potential stressor events noted throughout each day. Monday again remains a consistent high value performer across all volunteers.

Fig. 151 winter indicates an upward trend but this was due in the main to the values measured during Thurs. Two significant stressor events occurred around the lunchtime period due to the volunteer having 1/2-day leave and finishing early. Other days indicated similar trend profiles consistent with expectations.

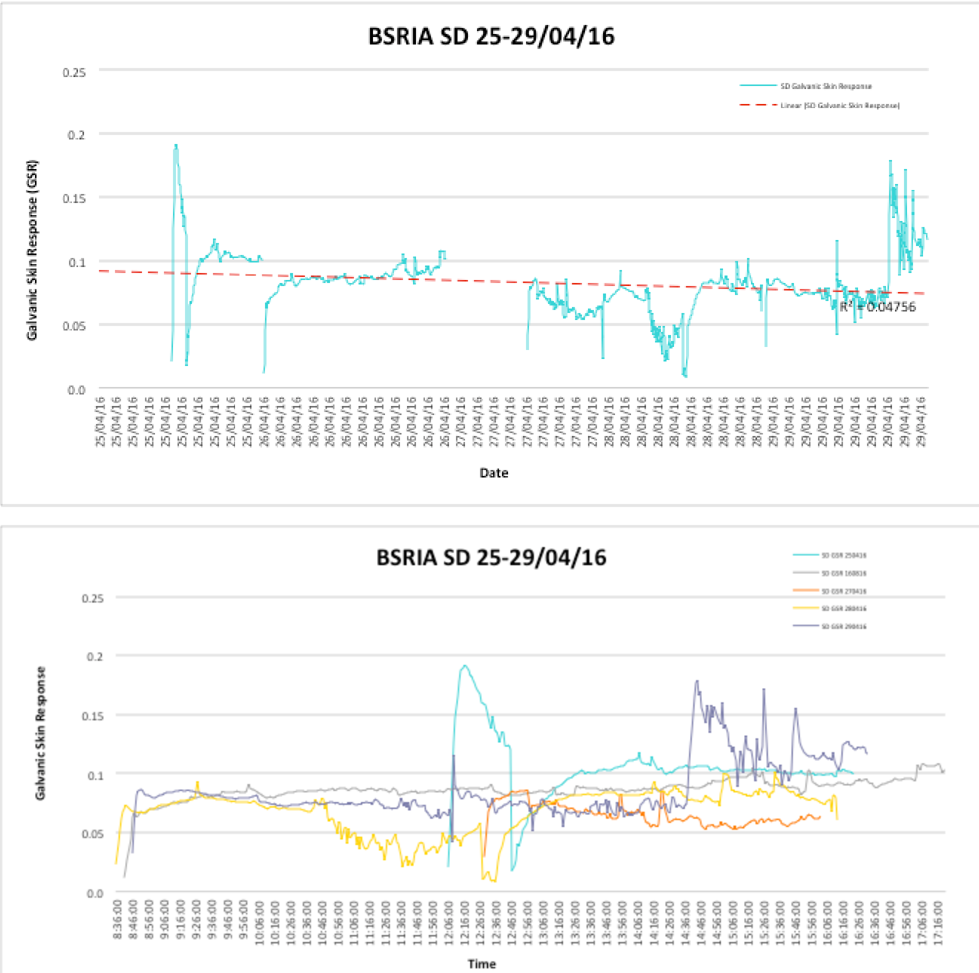


Fig. 148 – SD GSR Daily and Weekly Measured Values April 2016 (Spring)

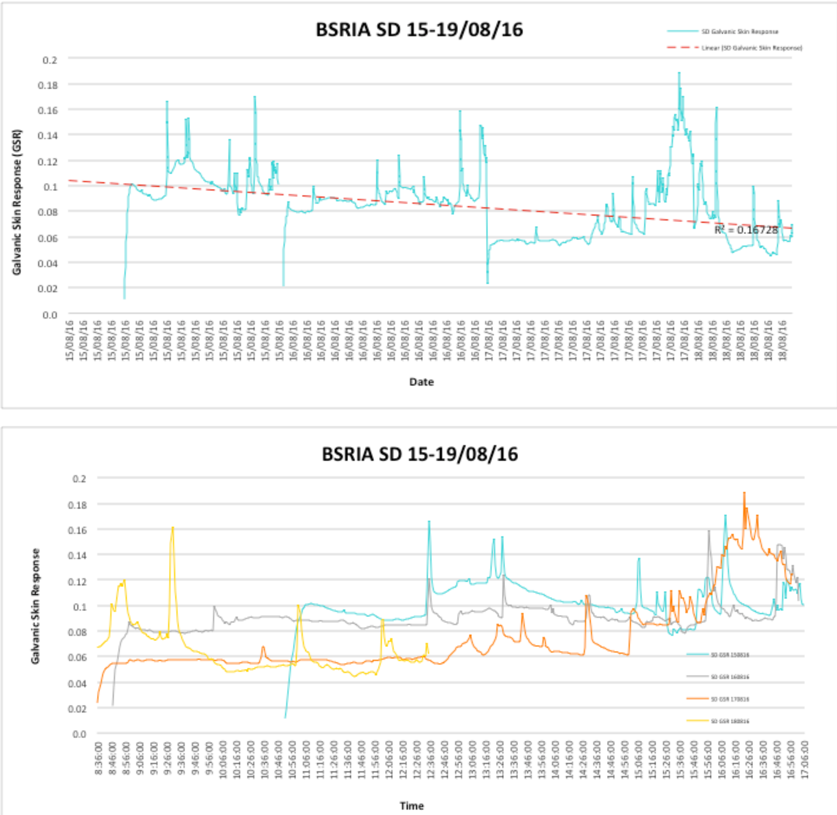


Fig. 149 – SD GSR Daily and Weekly Measured Values August 2016 (Summer)

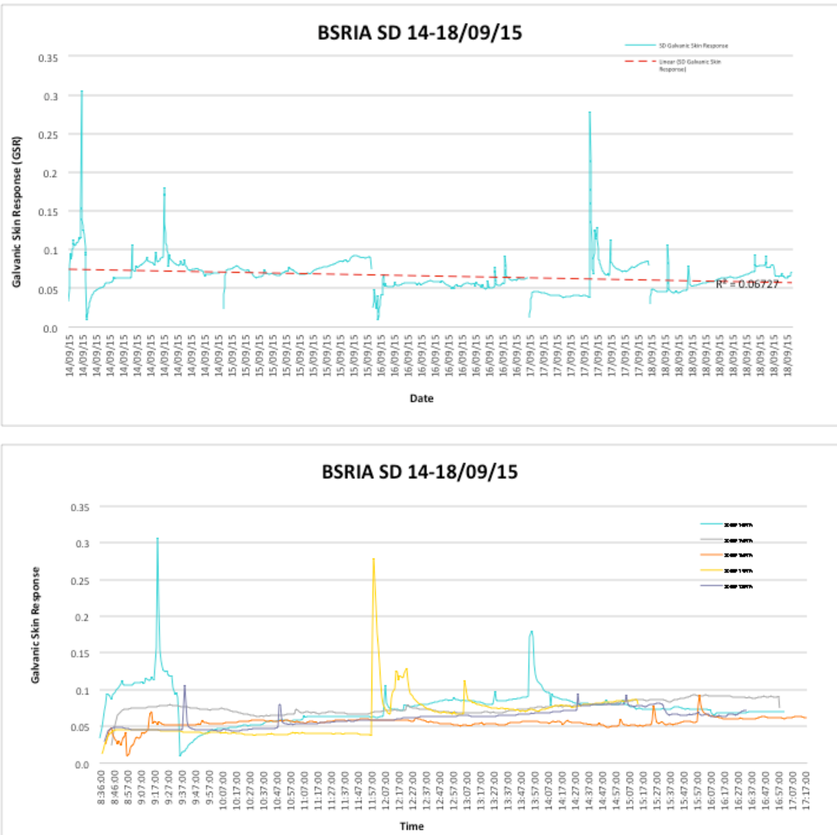


Fig. 150 – SD GSR Daily and Weekly Measured Values September 2015 (Autumn)

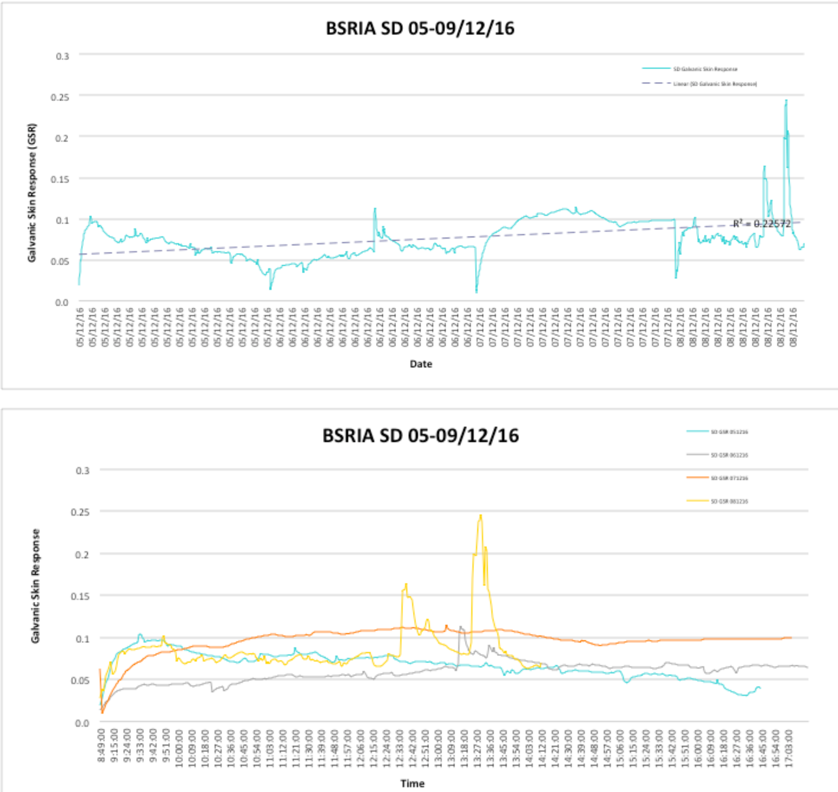


Fig. 151 – GSR Daily and Weekly Measured Values December 2016 (Winter)

5.4.8 BSRIA Volunteer 1 (DD & SB)

Table 54 indicates the measured data obtained from volunteer (DD & SB). Unfortunately volunteer SB was unable to continue the monitoring and was replaced by volunteer DD. Neither volunteer however, were available for the autumn period, and therefore no values were recorded for this period. Volunteer SB was a non-smoking female of weight 59.0kg height 157.5cm and BMI of 23.8. Volunteer DD was a non-smoking female of weight 55.3kg height 157.5cm and BMI of 22.3. This information is used within the Sensewear software to calculate the energy expended and metabolic equivalent.

Volunteer (SB) was replaced by DD and only provided 25hrs 24mins armband on body time (16%) from an expected research time of 160 hrs (8hrs/day x5-days/wk x4 seasonal periods). This volunteer also missed 1-day of measurements 28/04/16. Volunteer (DD) provided a total armband on body time of 71hrs 6mins (44%). Both volunteers provided a total on body research time of 96hrs 30mins (60%) which is still considered acceptable. The values presented below are therefore achieved across two individuals.

The average skin temperature noted within Table 54 across spring, summer and winter would support the environmental design of the space being of good quality given the natural ventilation and heating provided within the space, the skin temperature remaining very consistent across the seasonal changes. This is also supported by the near body temperature values for the same periods, but in addition would support the armband to be preforming well in terms of relative measurement consistency. Variance and standard deviation are small supporting the possibility that both parameters would be suitable for building system feedback acceptance. The Weekly (Seasonal) Average Skin Temperature of 32.82 deg.C applied to each seasonal weekly average value indicates a 0.81% increase during Spring; -0.52% decrease during Summer; N/A during Autumn; and -0.1% decrease during Winter. Across all x4 seasons Maximum values range 1.91% during winter to 3.74% during spring with Minimum values ranging between -3.23% during summer to -0.77% during spring.

Near Body Temperature measured values are also very consistent across the x4 seasons with acceptable variance and standard deviation values. The Weekly (Seasonal) Average Near Body Temperature of 30.06deg.C applied to each seasonal weekly average value indicates a -0.81% decrease during Spring; 0.40% increase during Summer; N/A during Autumn; and 0.31% increase during Winter. Across all x4 seasons Maximum figures range 3.70% during spring to 7.94% during winter with Minimum figures ranging between -9.33% during winter to 3.13% during summer.

Heat flux average values although relatively consistent overall between the seasons the graphical representation would propose that this physiological measurement is not sufficiently accurate to use within any potential feedback system. This is further supported in terms of variance, and is due primarily to the location of the device and the clothing worn by the volunteer. Significant variance exists seasonally however daily variations are relatively consistent. The Weekly (Seasonal) Average Heat Flux (Average) of 97.17W/m^2 applied to each seasonal weekly average value indicates a 20.77% increase during Spring; -10.82% decrease during Summer; N/A during Autumn; and -4.28% decrease during Winter. Across all x4 seasons Maximum figures range 4.98% summer to 26.32% during winter with Minimum figures ranging between -98.33% winter to 24.36% during spring.

Galvanic Skin Response is represented in scientific notation and presents a relatively consistent seasonal relationship with acceptable variance and standard deviation. The Weekly (Seasonal) Average Galvanic Skin Response (µS) of 1.26E-01applied to each seasonal weekly average value indicates a 48.35% increase during Spring; -8.70% decrease during Summer; N/A during Autumn; and -37.47% decrease during Winter. Across all x4 seasons Maximum figures range -42.98% during winter to 145.22% during spring with Minimum figures ranging between -58.92% during spring to -32.62% during winter

Energy expended and metabolic rate are calculated parameters and are seasonally consistent with acceptable variance and standard deviation. The Weekly (Seasonal) Average Energy Expended value 6.43 (KJ) applied to each seasonal weekly average value indicates a -4.13% decrease during Spring; -1.39% increase during Summer; N/A during Autumn; and 5.87% increase during Winter. Across all x4 season's Maximum figures range -13.01% during spring to 35.68% during winter with Minimum values ranging between -9.64% during summer to -2.90% during spring. The Weekly (Seasonal) Average Metabolic Equivalent value 1.64 (kCal/Kg/hr) applied to each seasonal weekly average value indicates a -8.36% decrease during Spring; 0.43% increase during Summer; N/A during Autumn; and 7.82% increase during winter. Across all x4 season's Maximum figures range -17.10% during spring to 37.74% during winter with Minimum figures ranging between -7.76% during summer to 1.05% during winter. Step No.s are indicated only.

Sensewear Armband - Daily, Weekly & Seasonal Summary Data

Volunteers - DD & SB

BSRIA - Bracknell - UK

Day	Date	Agent	Total Body (hrs:mins)	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average) (W/m2)				
Analysis 1				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	25/04/16		5:16	33.71	34.91	28.81	1.34	1.16	30.50	31.99	23.44	1.58	1.26	115.71	183.19	90.13	129.61	11.38
Tues	26/04/16		6:16	33.13	34.14	28.36	0.85	0.92	29.87	31.29	24.97	0.83	0.91	117.00	139.56	70.60	82.62	9.09
Wed	27/04/16		6:04	32.60	33.71	27.59	0.88	0.94	29.11	30.86	23.83	0.90	0.95	124.66	160.38	96.59	96.24	9.81
Thurs	28/04/16	SB	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fri	29/04/16		7:48	32.91	35.35	28.05	1.17	1.08	29.78	33.15	22.84	2.05	1.43	112.01	176.06	78.46	217.72	14.76
Week 1	**Spring**		**25:24**	**33.09**	**35.35**	**27.59**	**0.04**	**0.10**	**29.81**	**33.15**	**22.84**	**0.25**	**0.22**	**117.35**	**183.2**	**70.6**	**2,767.28**	**2.18**
Analysis 2				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	15/08/16		8:15	33.87	35.33	28.60	0.69	0.83	31.26	34.07	24.83	1.50	1.22	93.68	167.39	43.46	358.53	18.93
Tues	16/08/16		8:36	32.33	33.82	27.38	0.76	0.87	29.76	31.80	24.79	1.12	1.06	91.40	161.18	53.33	198.61	14.09
Wed	17/08/16		9:22	32.25	33.93	26.90	0.75	0.86	29.97	31.71	25.07	0.98	0.99	81.10	136.12	43.46	254.23	15.94
Thurs	18/08/16	DD	8:24	32.61	33.48	26.90	0.63	0.80	29.91	31.42	25.07	0.88	0.94	96.66	138.88	45.48	163.58	12.79
Fri	19/08/16		6:35	32.19	33.12	26.90	0.61	0.78	30.01	31.14	25.07	0.60	0.78	77.47	105.97	47.04	104.76	10.24
Week 2	**Summer**		**41:12**	**32.65**	**35.33**	**26.90**	**0.00**	**0.04**	**30.18**	**34.07**	**24.79**	**0.09**	**0.15**	**86.66**	**167.4**	**43.46**	**7,440.03**	**2.93**
Analysis 3				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	14/09/15																	
Tues	15/09/15																	
Wed	16/09/15																	
Thurs	17/09/15	N/A	N/A	**No Volunteers available during the period**														
Fri	18/09/15																	
Week 3	**Autumn**																	
Analysis 4				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Mon	05/12/16		5:55	33.07	33.73	28.87	0.36	0.60	29.43	30.62	23.08	1.04	1.02	130.55	201.41	103.04	473.92	21.77
Tues	06/12/16		9:57	33.55	34.73	27.82	0.46	0.68	32.18	34.50	23.08	1.57	1.25	47.96	159.94	3.45	622.18	24.94
Wed	07/12/16		8:18	33.18	34.64	27.11	0.39	0.62	30.67	33.50	21.79	1.94	1.39	89.60	183.36	0.95	1,057.66	32.52
Thurs	08/12/16	DD	5:44	31.27	32.13	28.13	0.43	0.66	28.32	29.46	24.56	1.07	1.04	103.92	159.38	62.00	383.54	19.58
Fri	09/12/16		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	**Winter**		**29:54**	**32.77**	**34.73**	**27.11**	**0.00**	**0.03**	**30.15**	**34.5**	**21.79**	**0.14**	**0.16**	**93.01**	**201.4**	**0.95**	**66,997.05**	**4.90**
Weekly (Seasonal) Average Summary (x4 wks)			**BSRIA (SB & DD)**	**32.82**	**34.08**	**27.80**			**30.06**	**31.96**	**24.03**			**97.17**	**159.45**	**56.77**		

Day	Date	Galvanic Skin Response (GSR) (µS)					Energy Expended (KJ)					Metabolic Rate (kCal/Kg/hr)					Steps (No.)
Analysis 1		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	25/04/16	1.78E-01	2.76E-01	2.42E-02	1.65E-03	4.06E-02	6.83	20.71	4.33	13.14	3.62	1.66	5.04	1.05	0.78	0.88	3,053
Tues	26/04/16	1.90E-01	2.39E-01	1.83E-02	4.70E-04	2.17E-02	6.26	19.61	4.36	8.79	2.96	1.52	4.77	1.06	0.52	0.72	1,634
Wed	27/04/16	1.58E-01	1.97E-01	3.44E-02	3.57E-04	1.89E-02	5.68	18.17	4.09	2.36	1.54	1.38	4.42	0.99	0.14	0.37	953
Thurs	28/04/16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Fri	29/04/16	2.19E-01	3.00E-01	1.04E-01	3.00E-04	1.73E-02	5.90	21.67	4.00	7.66	2.77	1.43	5.27	0.97	0.45	0.67	2,225
Week 1	**Spring**	**1.86E-01**	**3.00E-01**	**1.83E-02**	**3.08E-07**	**9.36E-03**	**6.17**	**21.67**	**4.00**	**14.75**	**0.76**	**1.50**	**5.27**	**0.97**	**0.05**	**0.18**	**1,966**
Analysis 2		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	15/08/16	1.02E-01	4.74E-01	2.12E-02	4.21E-03	6.49E-02	6.12	28.10	3.87	12.23	3.50	1.59	7.28	1.00	0.82	0.91	3,529
Tues	16/08/16	1.98E-01	1.08E+00	8.65E-02	5.28E-03	7.27E-02	6.52	24.95	3.51	13.72	3.70	1.69	6.47	0.91	0.92	0.96	4,440
Wed	17/08/16	4.37E-02	7.47E-01	2.34E-02	1.34E-03	3.66E-02	6.56	28.32	3.66	13.28	3.64	1.70	7.34	0.95	0.89	0.94	4,340
Thurs	18/08/16	1.22E-01	8.73E-01	4.40E-02	4.71E-03	6.86E-02	6.63	22.66	3.80	10.99	3.31	1.72	5.87	0.98	0.74	0.86	4,660
Fri	19/08/16	1.08E-01	7.47E-01	5.71E-02	4.22E-03	6.50E-02	5.88	19.99	3.75	3.98	1.99	1.52	5.18	0.97	0.27	0.52	1,652
Week 2	**Summer**	**1.15E-01**	**1.08E+00**	**2.12E-02**	**1.86E-06**	**1.28E-02**	**6.34**	**28.32**	**3.51**	**12.65**	**0.63**	**1.64**	**7.34**	**0.91**	**0.06**	**0.16**	**3,724**
Analysis 3		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	14/09/15																
Tues	15/09/15																
Wed	16/09/15																
Thurs	17/09/15																
Fri	18/09/15																
Week 3	**Autumn**																
Analysis 4		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Mon	05/12/16	9.03E-02	1.66E-01	6.30E-02	5.00E-04	2.24E-02	6.82	33.79	3.77	31.94	5.65	1.77	8.76	0.98	2.14	1.46	2,953
Tues	06/12/16	8.74E-02	1.71E-01	4.10E-02	1.19E-03	3.45E-02	6.90	30.88	3.86	24.16	4.92	1.79	8.00	1.00	1.62	1.27	1,067
Wed	07/12/16	6.85E-02	2.22E-01	3.00E-02	4.69E-04	2.17E-02	6.45	28.77	3.77	18.59	4.31	1.67	7.46	0.98	1.25	1.12	3,793
Thurs	08/12/16	6.77E-02	2.52E-01	3.22E-02	4.00E-04	2.00E-02	7.07	26.21	3.77	20.77	4.56	1.83	6.79	0.98	1.39	1.18	3,534
Fri	09/12/16	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	**Winter**	**7.85E-02**	**2.52E-01**	**3.00E-02**	**1.03E-07**	**5.77E-03**	**6.81**	**33.79**	**3.77**	**25.66**	**0.51**	**1.76**	**8.76**	**0.98**	**0.12**	**0.13**	**2,837**
Weekly (Seasonal) Average Summary (x4 wks)		**1.26E-01**	**4.42E-01**	**4.46E-02**			**6.43**	**24.91**	**3.89**			**1.64**	**6.36**	**0.99**			**2,842**

Seasonal Weekly % Average difference			Skin Avge	Skin Max	Skin Min	Near Body Avge	Near Body Max	Near Body Min	Heat Flux Avge	Heat Flux Max	Heat Flux Min	GSR Avge	GSR Max	GSR Min	Energy Avge	Energy Max	Energy Min	Metabolic Avge	Metabolic Max	Metabolic Min	Steps
Week 1	*Spring*		0.81%	3.74%	-0.77%	-0.81%	3.70%	-4.97%	20.77%	14.89%	24.36%	48.35%	-32.20%	-58.92%	-4.13%	-13.01%	2.90%	-8.36%	-17.10%	-1.42%	-30.82%
Week 2	*Summer*	**BSRIA (SB & DD)**	-0.52%	3.67%	-3.23%	0.40%	6.59%	3.13%	-10.82%	4.98%	-23.44%	-8.70%	145.22%	-52.34%	-1.39%	13.69%	-9.64%	0.43%	15.45%	-7.76%	31.02%
Week 3	*Autumn*		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Week 4	*Winter*		-0.17%	1.91%	-2.49%	0.31%	7.94%	-9.33%	-4.28%	26.32%	-98.33%	-37.47%	-42.98%	-32.62%	5.87%	35.65%	-3.07%	7.82%	37.74%	-1.05%	-0.20%

Abbreviations

Avge ***Average mean value of all arguments***
Max ***Maximum value within data set***
Min ***Minimum value within data set***
Var ***Variance from the average mean across the data set***
SD ***Standard Deviation from the average mean value across all data sets***
N/A ***Volunteer Not Available***

Table 54 - Sensewear Armband Measured Values – Volunteer (SB & DD)

Fig's. 152-155 represents the weekly and seasonal graphical output of the relevant measured physiological values as summarised within Table 55 As expected the skin temperature and near body temperature are very similarly related given the location of the armband sensors. The linear trend line and R^2 values indicate a relatively consistent temperature over the individual weekly assessed periods with minimal % seasonal adjustment as defined earlier.

Heat Flux average is again a more variable set of values with greater R^2 values and significant inclination of the trend line. Spring and winter periods indicate a slight decreasing trend, however, the summer and autumn period indicate a more level trend. An analysis of ambient relationships is provided within Chapter 6.

Fig's 156-159 represent a daily assessment of Skin and Near Body temperature and Heat Flux average to offer a more granular daily review across the seasonal periods.

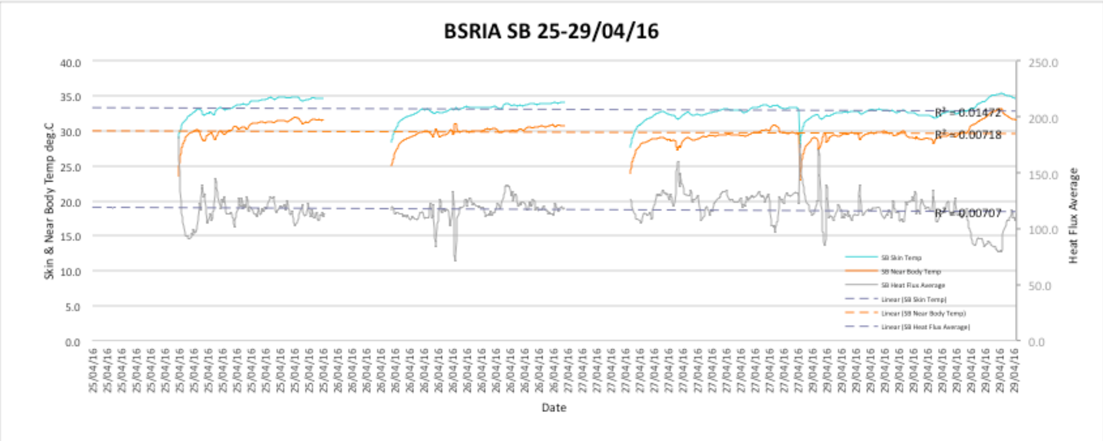


Fig. 152 – SB Seasonal Skin & Near Body Temperature and Heat Flux – April 2016 (Spring)

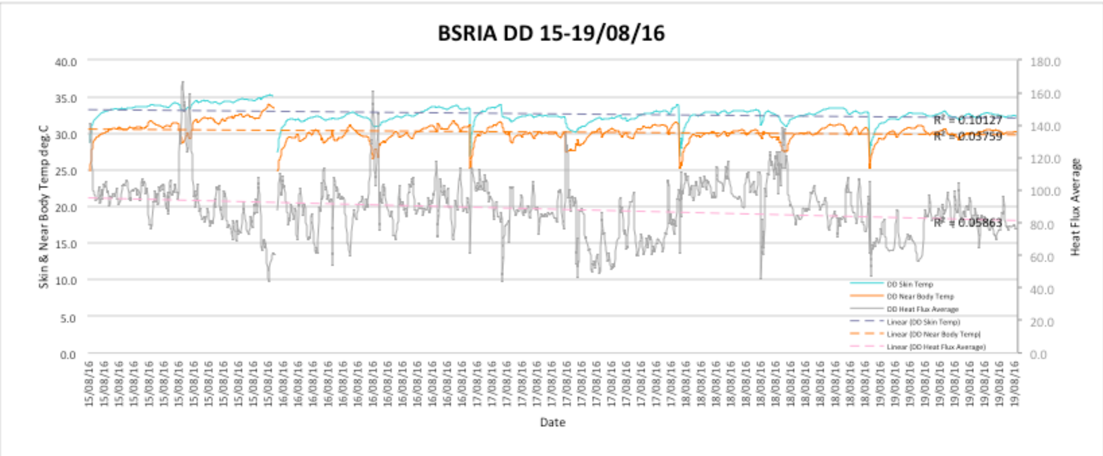


Fig. 153 – DD Seasonal Skin & Near Body Temperature and Heat Flux – August 2016 (Summer)

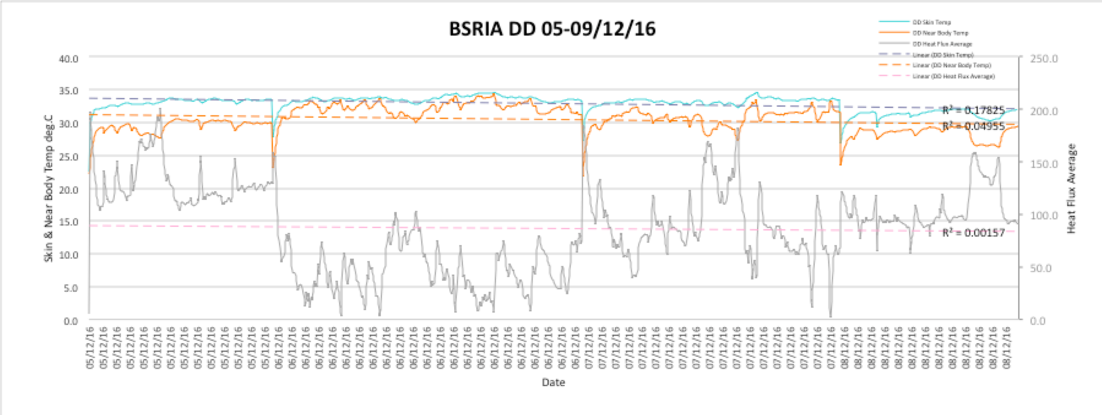
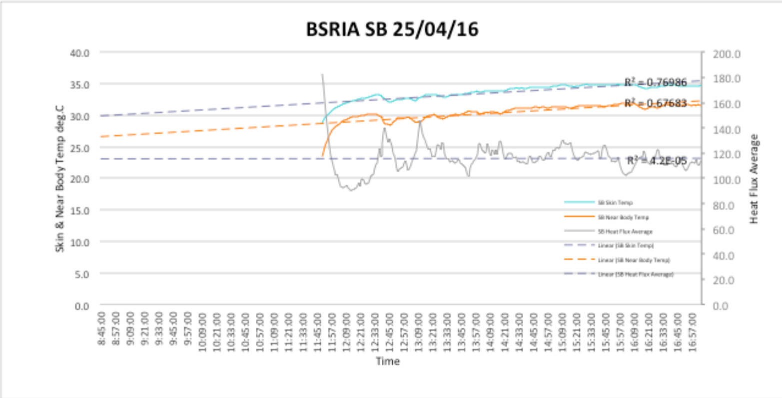
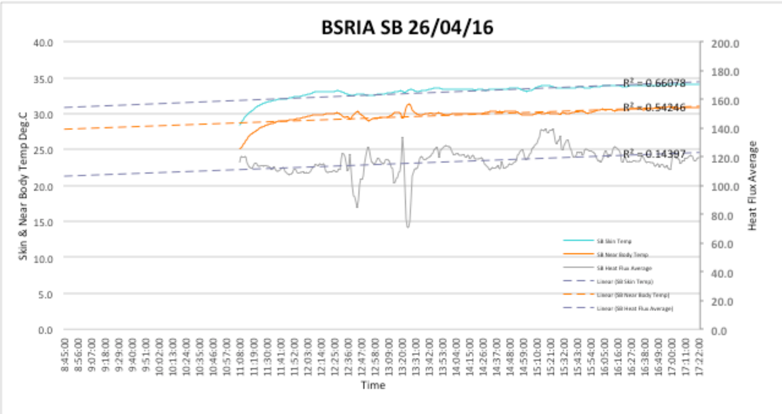


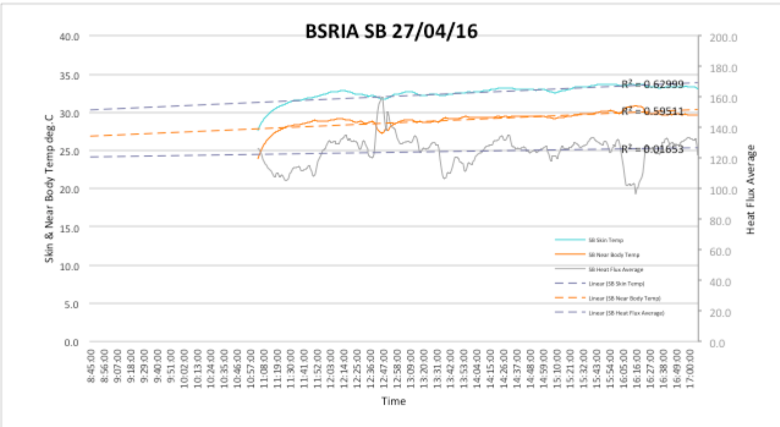
Fig. 154 – DD Seasonal Skin & Near Body Temperature and Heat Flux – December 2016 (Winter)

Within each of Fig's 152-154 the Skin and Near Body temperature trends actually reduce very slightly throughout the day not seen across other volunteers but remain within normal expected physical body temperature expectations. The daily graphs Fig's 155-158 however indicate the daily increases throughout each day but overall the trend is slightly downward or level.

Heat flux average trend is relatively level across the measured seasons and offers similar responses to the other BSRIA volunteers.







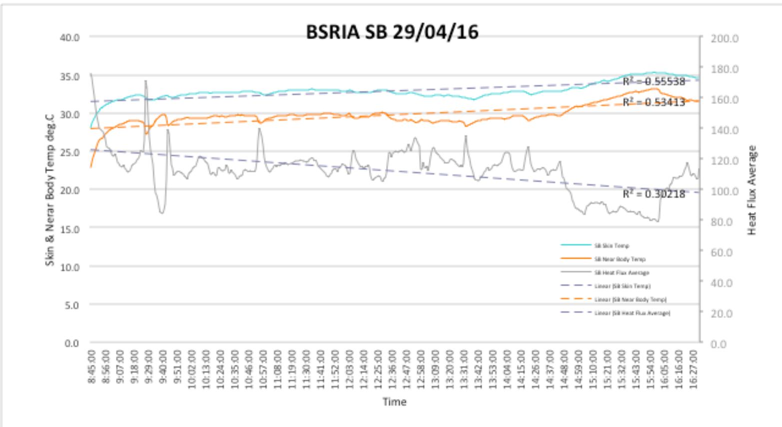


Fig. 155 – SB Daily Skin & Near Body Temperature and Heat Flux Values April 2016 (Spring)

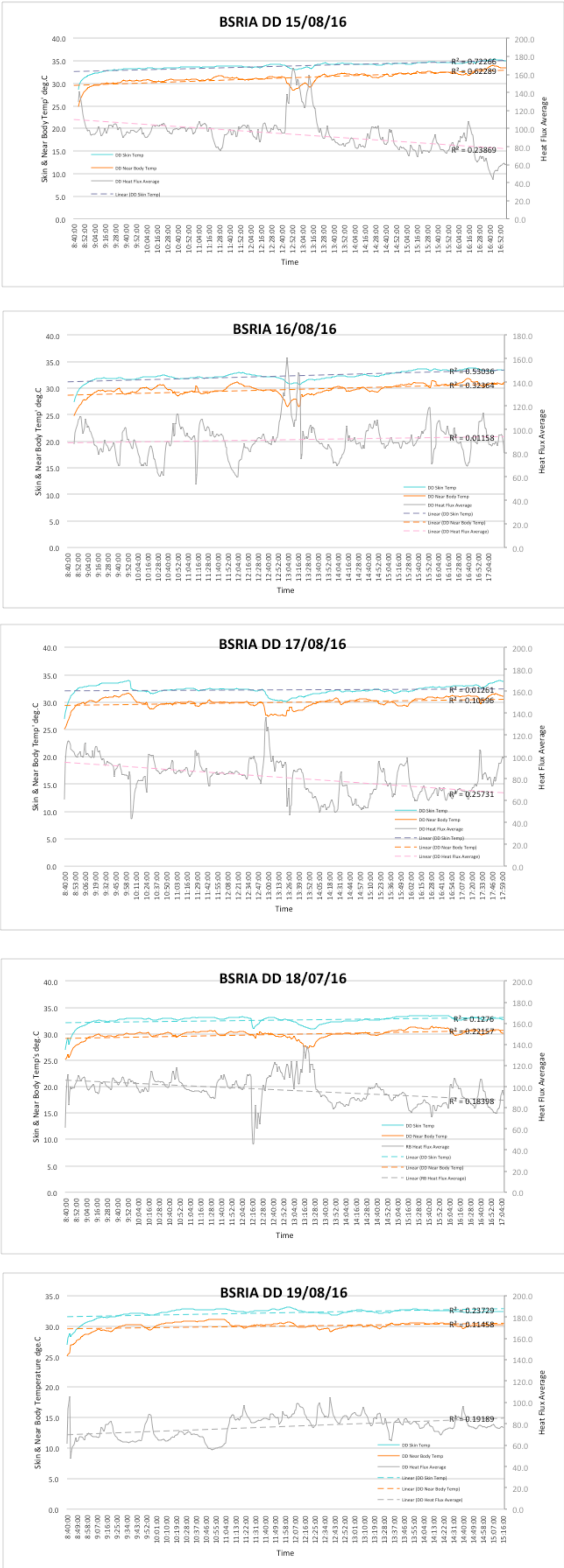


Fig. 156 – DD Daily Skin & Near Body Temperature and Heat Flux Values August 2016 (Summer)

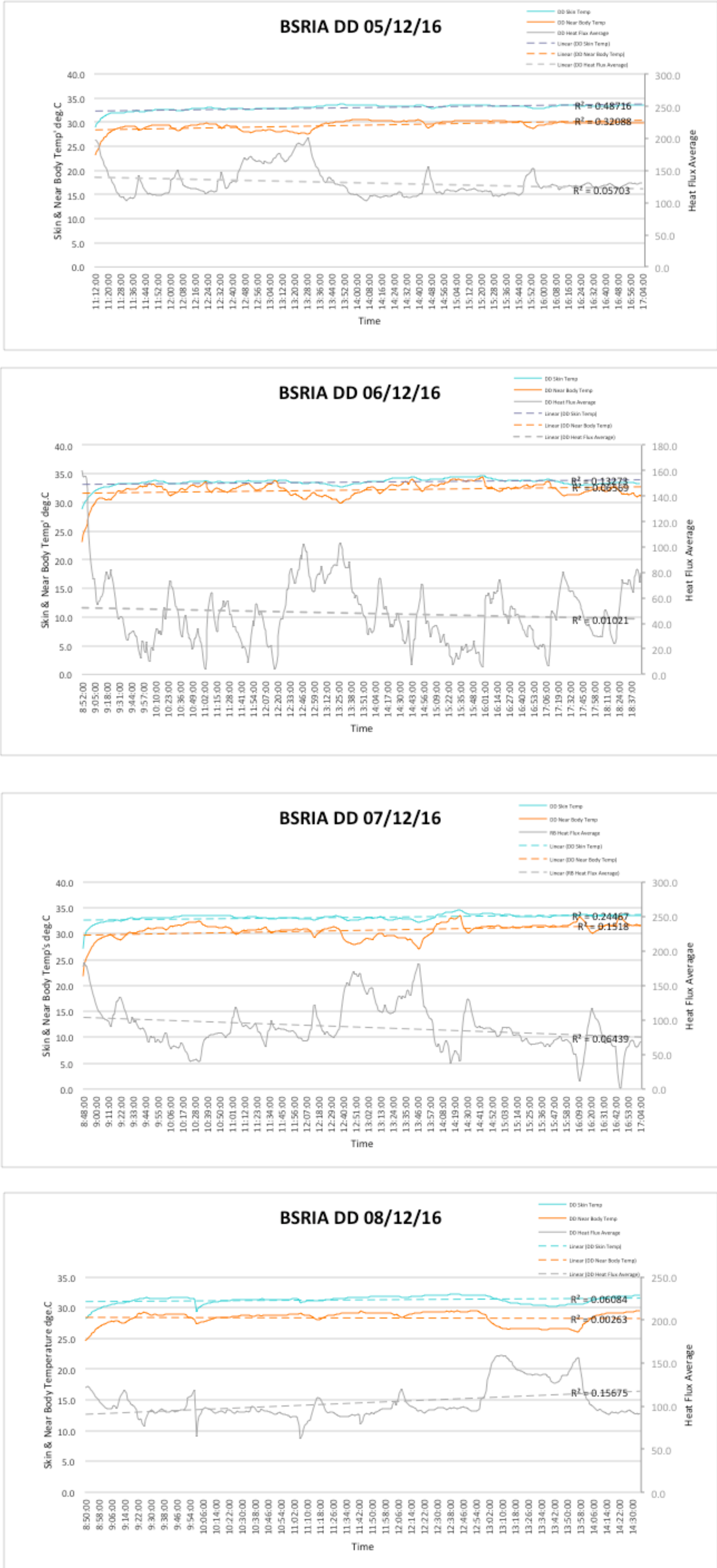
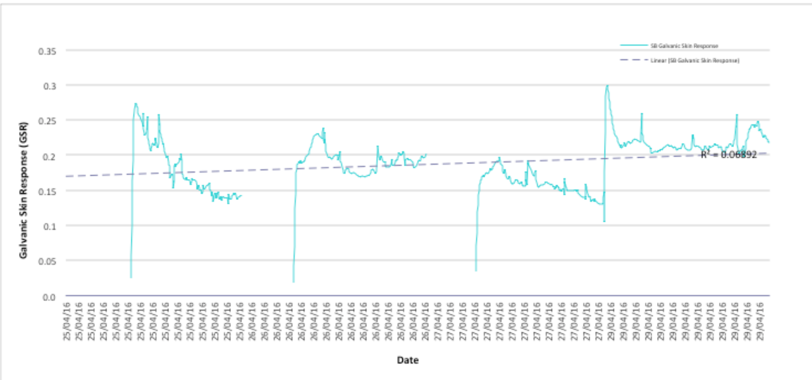


Fig. 157 – DD Daily Skin & Near Body Temperature and Heat Flux Values December 2016 (winter)

Fig's. 158-160 represents Galvanic Skin Response and indicate the equivalent seasonal periods. As the armband is worn on a daily basis, it is important to note the sharp increase at the start of the day as the armband is fitted and the stress of arriving at work and settling down for the day ahead. No values were recorded fro autumn. The graphs for spring (volunteer SB) and summer and winter (volunteer DD) indicated two different weekly trends. SB indicated and overall upward trend fro the week (4-days) where DD on both periods indicated a downward trend in GSR values – summer 5-days; winter 4-days. Fig. 158 for the ***spring*** period (SB) individual daily trends indicated a downward trend, however, the Friday shows a similar profile but significantly higher GSR values driving the overall weekly trend upwards. Fig. 159 ***summer*** period (DD) similar daily profiles exist, however the profiles are different to (SB). The sharp increases in daily start GSR values are consistent Mon-Fri, however the remainder of the day are very consistent values except for lunchtime periods. Tuesday displays higher GSR values over the day, however the overall weekly trend is downwards Mon-Fri. There was no data recorded for the autumn period due to research engineer being unavailable. Fig. 160 ***winter*** (DD) indicates a similar daily set of trends as the summer period. Tuesday again displays a higher set of daily values and upward trend, however the overall weekly trend is again downwards Mon-Fri.



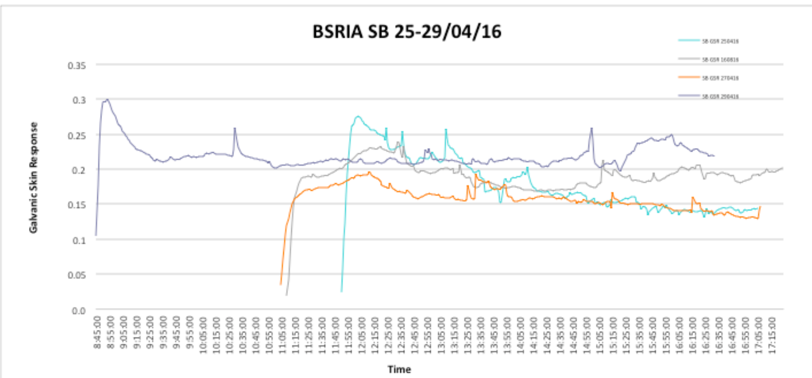


Fig. 158 – DD GSR Daily and Weekly Measured Values April 2016 (Spring)

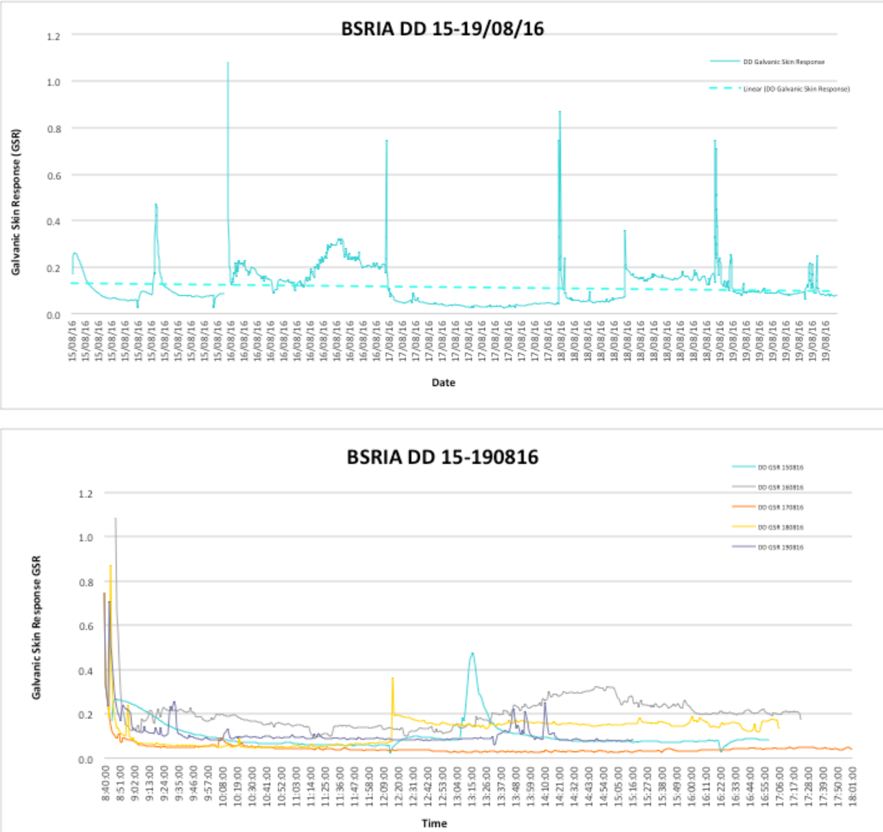


Fig. 159 – DD GSR Daily and Weekly Measured Values August 2016 (Summer)

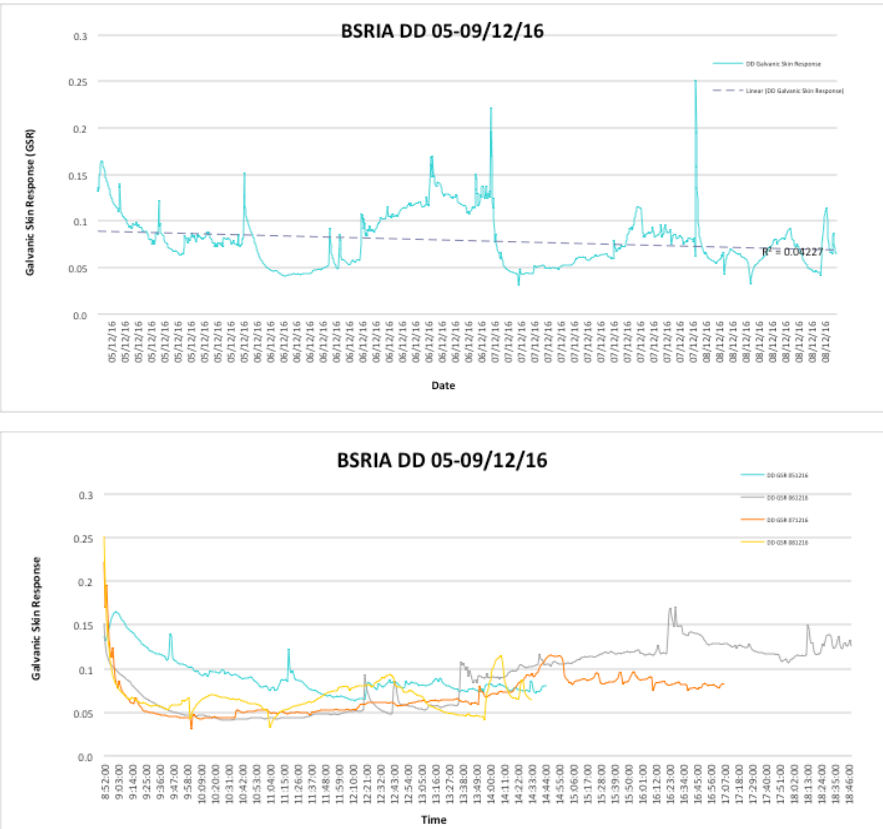


Fig. 160 – DD GSR Daily and Weekly Measured Values December 2016 (Winter)

5.5 Armband Seasonal Summary Data

Table 55 provides a summary of all individually measured parameters and values across each set of volunteers (x8) and for each site. The table summarise all the volunteer values as detailed within the previous individual tables, enabling a comparative assessment of seasonal values. Table 56 summarises the key physiological measured values and the site ambient condition, and further environmental data analysis is provided within Chapter 6.

The measured physiological values within Table 56 provide a site comparative analysis of each site and how individuals compare to each other. The two sites are similar in basic design, but are of different technological age. However, the values measured indicate a close relationship with each site and each volunteer based upon a average assessment. The seasonal average values relative to each respective site average values are all within +/- 5% of each other, suggesting the measured average values per site are within an acceptable tolerance for assumption. The consistent values relative to the parameters over the seasons support the accuracy of the measuring device and the quality of the data.

The min and max values are for skin & near body temperature are within +/- 5%, however the min value for heat flux vary significantly around the average mean of +/- 66%. Significant levels of variance were noted with respect to heat flux which is consistent across both sites, but by different degree.

Galvanic Skin Response (GSR) average values indicate +/- 1.64%, however, max and min values indicate variance around the mean of +/- 18.29% and +/- 43.31%. Significant variance exists however there is evidence of satisfactory values of standard deviation.

Energy expended and metabolic equivalent (average) as calculated values within the software can be seen again to closely aligned across individuals and as sites. Min and Max values are also closely aligned +/- 7%.

Table 57 details skin and near body temperature and heat flux average to internal and external ambient conditions, however further analysis is provided within Chapter 6. The review of site average internal conditions indicated a wet bulb globe temperature of +/- 3.27%; air temperature of +/- 1.95%; air dry globe temperature of +/- 0.35%; relative humidity of +/- 5.37%. External conditions were not assessed in direct relationship as they varied significantly between seasons and no control could be administered. The internal design conditions are seen to be more acceptably relevant as the internal conditions are controlled to meet design criteria.

Sensewear Armband - Seasonal Summary Data

Measured Physiological Results

BSRIA - Bracknell - UK
5 Plus Architects - Manchester - UK

Season	Date	Agent	Firm	Skin Temperature (deg.C)					Near Body Temperature (deg.C)					Heat Flux (Average)				
				Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD
Spring	25-29/04/16	SB & DD	BSRIA	33.09	35.35	27.59	0.04	0.10	29.81	31.99	22.84	0.25	0.22	117.35	183.19	70.60	2,767.28	2.18
Summer	15-19/08/16			32.65	35.33	26.90	0.00	0.04	30.18	34.07	24.79	0.09	0.15	86.66	167.39	43.46	7,440.03	2.93
Autumn	15-18/09/15			N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Winter	05-09/12/16			32.77	34.73	27.11	0.00	0.03	30.15	34.50	21.79	0.14	0.16	93.01	201.41	0.95	66,997.05	4.90
Annual				**32.82**	**35.35**	**26.90**			**30.06**	**34.50**	**21.79**			**97.17**	**159.45**	**56.77**		
Spring	25-29/04/16	MA-H	BSRIA	32.16	34.75	27.51	0.02	0.11	29.27	33.39	24.22	120.85	0.17	102.65	186.84	32.53	14,311.26	4.06
Summer	15-19/08/16			32.44	35.21	29.29	0.15	0.25	30.11	33.75	26.41	0.25	0.27	83.00	144.97	-83.38	96,410.63	7.23
Autumn	15-18/09/15			32.36	34.52	27.19	0.38	0.31	29.45	32.99	23.00	0.95	0.39	103.41	179.62	45.09	30,729.61	5.77
Winter	05-09/12/16			31.40	32.79	20.61	0.13	0.25	28.58	31.18	19.80	0.28	0.29	99.81	176.17	20.50	2,725.10	1.76
Annual				**32.12**	**35.21**	**20.61**			**29.39**	**33.75**	**19.80**			**97.39**	**186.84**	**-83.38**		
Spring	25-29/04/16	SD	BSRIA	33.01	34.68	27.88	0.09	0.17	29.81	32.06	22.19	0.48	0.50	111.06	226.13	55.37	9,121.23	2.86
Summer	15-19/08/16			32.39	37.55	27.40	0.40	0.34	29.42	40.47	24.32	3.90	0.85	108.05	170.89	-135.50	933,623.88	13.92
Autumn	15-18/09/15			32.55	34.96	26.92	0.13	0.18	29.63	32.35	21.89	0.53	0.27	103.72	174.25	58.29	29,314.91	4.62
Winter	05-09/12/16			31.40	32.79	20.61	0.13	0.25	28.58	31.18	19.80	0.28	0.29	99.82	176.17	20.50	2,511.69	1.69
Annual				**32.38**	**37.55**	**20.61**			**29.40**	**40.47**	**19.80**			**105.96**	**226.13**	**-135.50**		
Spring	25-29/04/16	IW	BSRIA	32.47	36.88	26.90	0.30	0.22	29.52	38.20	20.61	1.64	0.41	105.13	206.66	-57.12	124,145.99	8.04
Summer	15-19/08/16			33.01	34.87	28.64	0.08	0.19	30.44	33.35	25.85	0.10	0.18	88.78	133.39	30.12	1,372.94	1.75
Autumn	15-18/09/15			31.75	33.82	26.22	0.08	0.16	28.46	30.23	20.42	0.03	0.09	117.10	188.43	95.09	2,238.24	1.87
Winter	05-09/12/16			32.17	33.23	28.51	0.04	0.16	29.30	30.71	23.99	0.09	0.20	101.95	196.79	77.82	1,220.92	1.41
Annual				**32.48**	**36.88**	**26.22**			**29.61**	**38.20**	**20.42**			**102.56**	**206.66**	**-57.12**		
Spring	14-18/03/16	CH	5Plus	31.80	33.64	27.36	0.18	0.26	29.40	29.40	24.85	0.14	0.22	86.82	164.51	18.15	17,235.21	4.36
Summer	13-17/07/15			31.73	34.80	27.03	0.10	0.18	29.47	29.47	24.77	0.08	0.16	79.34	-99.58	59.37	176.90	13.30
Autumn	16-20/11/15			32.82	34.98	27.92	0.02	0.06	30.24	33.46	24.11	0.02	0.07	92.13	173.09	742.92	46,818.72	5.16
Winter	12-16/12/16			30.61	32.99	25.71	0.08	0.17	28.56	32.30	20.89	0.09	0.15	71.73	180.71	9.56	8,771.52	2.89
Annual				**31.74**	**34.98**	**25.71**			**29.42**	**33.46**	**20.89**			**82.50**	**180.71**	**9.56**		
Spring	14-18/03/16	MHay	5Plus	34.28	35.56	28.09	0.05	0.13	32.91	34.96	23.89	0.34	0.24	48.49	164.59	-6.62	18,754.77	3.85
Summer	13-17/07/15			33.94	35.93	29.76	0.02	0.10	31.87	35.24	25.99	0.06	0.12	80.87	159.34	6.21	9,209.57	2.95
Autumn	16-20/11/15			34.23	35.47	28.70	0.00	0.03	32.55	35.26	23.44	0.01	0.04	59.64	73.38	47.50	112.90	10.63
Winter	12-16/12/16			34.55	36.14	29.19	0.04	0.12	32.61	35.56	23.85	0.23	0.19	69.37	194.92	7.10	26,826.08	4.01
Annual				**34.25**	**36.14**	**28.09**			**32.48**	**35.56**	**23.44**			**64.59**	**194.92**	**-6.62**		
Spring	14-18/03/16	MHar	5Plus	32.37	33.32	29.44	0.00	0.06	29.70	32.59	24.13	0.05	0.20	95.30	211.09	45.59	16,004.06	4.47
Summer	13-17/07/15			32.20	33.07	31.43	0.36	0.60	29.10	30.24	28.19	0.54	0.73	108.94	166.90	59.62	5,435.97	2.50
Autumn	16-20/11/15			32.54	33.80	28.55	0.00	0.03	29.60	31.25	23.63	0.01	0.08	111.80	192.63	63.23	23,189.19	4.96
Winter	12-16/12/16			32.59	33.91	28.20	0.01	0.09	29.14	30.05	28.10	0.48	0.69	123.70	192.25	76.52	2,612.52	2.08
Annual				**32.42**	**33.91**	**28.20**			**29.38**	**32.59**	**23.63**			**109.94**	**211.09**	**45.59**		
Spring	14-18/03/16	RB	5Plus	34.03	35.54	27.53	0.18	0.23	30.74	33.06	22.49	0.85	0.40	118.54	235.74	83.89	28,488.25	4.32
Summer	13-17/07/15			32.81	34.11	27.49	0.15	0.24	29.89	31.82	24.52	0.24	0.27	105.12	181.47	49.64	7,042.81	3.16
Autumn	16-20/11/15			33.85	35.07	28.26	0.01	0.06	30.35	32.04	23.32	0.13	0.18	126.01	218.50	73.47	31,711.28	5.09
Winter	12-16/12/16			34.07	35.07	27.11	0.09	0.16	30.44	32.06	22.78	0.16	0.19	131.08	242.40	94.62	57,014.16	6.04
Annual				**33.69**	**35.54**	**27.11**			**30.36**	**33.06**	**22.49**			**120.19**	**242.40**	**49.64**		
Seasonal Average Summary			BSRIA	32.37	34.76	26.62			29.51	33.36	22.79			101.43	180.82	18.29		
			5 Plus	33.03	34.59	28.24			30.41	32.42	24.31			94.31	165.75	89.42		
Site Comparision Average Value				32.70	34.68	27.43			29.96	32.89	23.55			97.87	173.28	53.86		
Average (%) difference from Site Comparision Average Value			BSRIA	-1.00%	0.25%	-2.95%			-1.50%	1.43%	-3.22%			3.64%	4.35%	-66.04%		
			5 Plus	1.00%	-0.25%	2.95%			1.50%	-1.43%	3.22%			-3.64%	-4.35%	66.04%		

Season	Agent	Galvanic Skin Response (GSR)					Energy Expended (KJ)					Metabolic Rate					Steps
		Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Avge	Max	Min	Var	SD	Count
Spring	SB & DD	1.86E-01	3.00E-01	1.83E-02	3.08E-07	9.36E-03	6.17	21.67	4.00	14.75	0.76	1.50	5.27	0.97	0.05	0.18	1,966
Summer		1.15E-01	1.08E+00	2.12E-02	1.86E-06	1.28E-02	6.34	28.32	3.51	12.65	0.63	1.64	7.34	0.91	0.06	0.16	3,724
Autumn		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Winter		7.85E-02	2.52E-01	3.00E-02	1.03E-07	5.77E-03	6.81	33.79	3.77	25.66	0.51	1.76	8.76	0.98	0.12	0.13	2,837
Annual		**1.26E-01**	**4.42E-01**	**4.46E-02**			**6.43**	**24.91**	**3.89**			**1.64**	**6.36**	**0.99**			**2,842**
Spring	MA-H	5.76E-02	1.56E-01	9.52E-03	4.08E-04	2.82E-03	6.23	27.63	3.80	2.49	0.21	1.55	6.88	0.95	0.01	0.05	3,235
Summer		7.59E-02	2.48E-01	8.06E-03	6.93E-08	6.62E-03	6.07	21.96	3.94	5.62	0.46	1.51	5.47	0.98	0.02	0.11	2,900
Autumn		6.14E-02	1.41E-01	7.33E-03	3.95E-09	2.02E-03	6.24	26.11	3.82	29.90	1.07	1.53	6.40	0.94	0.11	0.26	2,676
Winter		7.71E-02	2.46E-01	9.52E-03	9.71E-08	7.03E-03	6.67	23.69	3.77	4.41	0.30	1.66	5.90	0.94	0.02	0.08	4,184
Annual		**6.75E-02**	**2.48E-01**	**7.33E-03**			**6.28**	**27.63**	**3.77**			**1.56**	**6.88**	**0.94**			**3,249**
Spring	SD	8.23E-02	1.92E-01	8.06E-03	7.03E-08	7.47E-03	6.66	28.54	4.23	7.17	0.49	1.32	5.64	0.84	0.01	0.10	1,889
Summer		8.25E-02	1.89E-01	1.10E-02	6.40E-08	6.00E-03	7.23	19.72	4.23	4.83	0.36	1.43	3.90	0.84	0.01	0.07	2,438
Autumn		6.59E-02	3.06E-01	8.79E-03	8.17E-08	8.18E-03	7.13	19.91	4.09	1.62	0.21	1.41	3.93	0.81	0.00	0.04	3,258
Winter		7.71E-02	2.46E-01	9.52E-03	9.71E-08	7.03E-03	6.67	23.69	3.77	4.41	0.30	1.66	5.90	0.94	0.02	0.08	4,184
Annual		**7.69E-02**	**3.06E-01**	**8.06E-03**			**6.92**	**28.54**	**3.77**			**1.45**	**5.90**	**0.81**			**2,942**
Spring	IW	1.15E-01	3.12E-01	7.33E-03	6.63E-07	9.86E-03	10.58	33.80	6.38	165.21	1.68	1.32	4.22	0.80	0.04	0.21	1,813
Summer		2.39E-01	8.75E-01	1.25E-02	5.17E-05	3.17E-02	10.65	35.05	6.46	14.98	0.53	1.33	4.38	0.81	0.00	0.07	1,958
Autumn		1.99E-01	8.40E-01	2.05E-02	1.28E-05	2.36E-02	10.91	33.52	6.46	108.30	1.33	1.36	4.19	0.81	0.03	0.17	2,980
Winter		1.35E-01	3.24E-01	8.06E-03	2.39E-06	1.75E-02	10.57	33.45	6.78	2.22	0.17	1.32	4.18	0.85	0.00	0.02	2,408
Annual		**1.74E-01**	**8.75E-01**	**7.33E-03**			**10.65**	**35.05**	**6.38**			**1.33**	**4.38**	**0.80**			**2,289**
Spring	CH	5.18E-02	7.47E-02	8.79E-03	7.61E-10	2.02E-03	5.79	27.94	3.71	21.43	1.43	1.49	6.85	0.91	0.14	0.27	2,715
Summer		5.73E-02	1.77E-01	9.52E-03	4.11E-08	7.01E-03	6.26	7.03	5.54	0.36	0.60	1.53	1.72	1.36	0.02	0.15	2,657
Autumn		4.86E-02	6.45E-02	9.52E-03	4.81E-11	6.38E-03	6.16	31.96	3.84	51.99	0.94	1.51	7.83	0.94	0.19	0.23	3,318
Winter		5.45E-02	8.94E-02	9.52E-03	4.52E-10	1.72E-03	6.37	27.58	3.75	17.05	0.61	1.56	6.76	0.92	0.06	0.15	4,228
Annual		**5.31E-02**	**1.77E-01**	**8.79E-03**			**6.15**	**31.96**	**3.71**			**1.53**	**7.83**	**0.91**			**3,230**
Spring	MHay	1.34E-01	2.87E-01	9.52E-03	4.01E-08	6.27E-03	8.53	43.38	5.98	6.22	0.44	1.23	6.23	0.86	0.00	0.06	1,431
Summer		9.68E-02	3.53E-01	2.05E-02	1.83E-07	9.70E-03	8.35	27.31	4.07	8.83	0.58	1.25	3.89	0.86	0.00	0.08	906
Autumn		1.07E-01	1.56E-01	8.05E-02	1.22E-03	3.49E-02	8.85	27.43	6.15	0.40	0.14	1.27	4.21	0.88	0.00	0.02	1,022
Winter		1.19E-01	2.13E-01	1.17E-02	1.18E-09	1.35E-03	9.06	9.44	8.56	0.13	0.36	1.30	4.58	0.86	0.01	0.13	1,608
Annual		**1.14E-01**	**3.53E-01**	**9.52E-03**			**8.70**	**43.38**	**4.07**			**1.26**	**6.23**	**0.86**			**1,242**
Spring	MHar	1.15E-01	2.15E-01	7.17E-02	3.41E-03	5.84E-02	4.38	31.50	0.03	12.82	1.23	1.77	7.68	1.05	0.21	0.31	3,731
Summer		1.02E-01	4.11E-01	9.52E-03	3.76E-07	9.66E-03	7.97	32.68	5.08	1.71	0.27	1.64	6.71	1.04	0.00	0.05	1,340
Autumn		8.10E-02	1.77E-01	1.03E-02	4.57E-08	5.86E-03	8.65	37.61	5.07	47.75	0.76	1.78	7.72	1.04	0.08	0.16	3,434
Winter		1.22E-01	2.37E-01	7.53E-02	3.51E-03	5.92E-02	8.06	33.66	5.07	68.00	1.50	1.70	7.31	1.04	0.11	0.28	2,113
Annual		**1.05E-01**	**4.11E-01**	**9.52E-03**			**7.27**	**37.61**	**0.03**			**1.72**	**7.72**	**1.04**			**2,655**
Spring	RB	1.55E-01	6.69E-01	1.25E-02	1.28E-05	3.41E-02	9.90	33.92	6.00	86.90	0.99	1.56	5.36	0.95	0.05	0.15	3,000
Summer		2.27E-01	3.71E-01	1.24E-01	1.00E-02	1.00E-01	10.30	41.20	6.24	53.73	0.83	1.54	6.14	0.93	0.03	0.12	3,364
Autumn		1.63E-01	4.54E-01	2.64E-02	7.15E-06	2.30E-02	10.69	39.99	6.00	69.54	0.81	1.69	6.32	0.95	0.04	0.13	3,231
Winter		6.75E-02	2.61E-01	2.27E-02	8.93E-08	7.80E-03	10.50	49.13	6.00	561.83	1.80	1.66	7.77	0.95	0.35	0.28	3,196
Annual		**1.53E-01**	**6.69E-01**	**1.25E-02**			**10.35**	**49.13**	**6.00**			**1.61**	**7.77**	**0.93**			**3,198**
Seasonal Average Summary (BSRIA)		1.10E-01	3.81E-01	1.26E-02			7.66	27.39	4.60			1.49	5.49	0.89			2,830
(5 Plus)		1.06E-01	2.63E-01	3.20E-02			8.12	31.36	5.07			1.53	6.07	0.97			2,581
Site Comparision Average Value		1.08E-01	3.22E-01	2.23E-02			7.89	29.38	4.83			1.51	5.78	0.93			2,705
Average (%) difference from Site Comparision Average Value (BSRIA)		1.64%	18.29%	-43.31%			-2.87%	-6.76%	-4.81%			-1.43%	-5.01%	-4.39%			4.60%
(5 Plus)		-1.64%	-18.29%	43.31%			2.87%	6.76%	4.81%			1.43%	5.01%	4.39%			-4.60%

Table 55 - Comparison of Site Physiological Measured Values

Sensewear Armband - Seasonal Summary Data

Measured Temperature Results

5 Plus Architects - Manchester - UK
BSRIA - Bracknell - UK

Season	Date	Agent	Firm	Skin Temp (deg.C)	Near Body Temp (deg.C)	Heat Flux (Average)	Internal Conditions: Wet Bulb Globe (deg.C)	Internal Conditions: Air (deg.C)	Internal Conditions: Air (Dry) Globe (deg.C)	Internal Conditions: %rh	External Values: Air (deg.C)	External Values: %rh
Seasonal Dates				Average Values								
Spring	14-18/03/16	CH	5 Plus	31.80	29.40	86.82	17.97	20.80	21.71	51.89	8.86	62.53
Summer	13-17/07/15			31.73	29.47	79.34	22.60	23.24	23.76	46.64	18.43	60.04
Autumn	16-20/11/15			32.82	30.24	92.13	17.68	21.79	22.12	55.96	10.20	75.07
Winter	12-16/12/16			30.61	28.56	71.73	16.66	21.88	22.15	45.67	10.27	74.14
Annual	Average			**31.74**	**29.42**	**82.50**	**18.72**	**21.93**	**22.43**	**50.04**	**11.94**	**67.94**
Spring	14-18/03/16	MHay	5 Plus	34.28	32.91	48.49						
Summer	13-17/07/15			33.94	31.87	80.87						
Autumn	16-20/11/15			34.23	32.55	59.64						
Winter	12-16/12/16			34.55	32.61	69.37						
Annual	Average			**34.25**	**32.48**	**64.59**						
Spring	14-18/03/16	MHar	5 Plus	32.37	29.70	95.30						
Summer	13-17/07/15			32.20	29.10	108.94						
Autumn	16-20/11/15			32.54	29.60	111.80						
Winter	12-16/12/16			32.59	29.14	123.70						
Annual	Average			**32.42**	**29.38**	**109.94**						
Spring	14-18/03/16	RB	5 Plus	34.03	30.74	118.54						
Summer	13-17/07/15			32.81	29.89	105.12						
Autumn	16-20/11/15			33.85	30.35	126.01						
Winter	12-16/12/16			34.07	30.44	131.08						
Annual	Average			**33.69**	**30.36**	**120.19**						
Spring	25-29/04/16	MA-H	BSRIA	32.16	29.27	102.65	15.44	21.55	21.53	35.95	10.15	54.42
Summer	15-19/08/16			32.44	30.11	83.00	19.77	25.68	25.09	45.59	21.03	67.99
Autumn	15-18/09/15			32.36	29.45	103.41	17.63	21.48	21.26	52.21	15.79	68.45
Winter	05-09/12/16			31.40	28.58	99.81	17.31	22.47	22.48	46.01	8.91	82.28
Annual	Average			**32.09**	**29.35**	**97.22**	**17.54**	**22.80**	**22.59**	**44.94**	**13.97**	**68.28**
Spring	25-29/04/16	IW	BSRIA	32.47	29.52	105.13						
Summer	15-19/08/16			33.01	30.44	88.78						
Autumn	15-18/09/15			31.75	28.46	117.10						
Winter	05-09/12/16			32.17	29.30	101.95						
Annual	Average			**32.35**	**29.43**	**103.24**						
Spring	25-29/04/16	SD	BSRIA	33.01	29.81	111.06						
Summer	15-19/08/16			32.39	29.42	108.05						
Autumn	15-18/09/15			32.55	29.63	103.72						
Winter	05-09/12/16			31.40	28.58	99.82						
Annual	Average			**32.34**	**29.36**	**105.66**						
Spring	25-29/04/16	DD & SB	BSRIA	33.09	29.81	117.35						
Summer	15-19/08/16			32.65	30.18	86.66						
Autumn	15-18/09/15			N/A	N/A	N/A						
Winter	05-09/12/16			32.77	30.15	93.01						
Annual				**32.84**	**30.05**	**99.00**						
Seasonal Average Summary			5 Plus	33.03	30.41	94.31	18.72	21.93	22.43	50.04	11.94	67.94
			BSRIA	32.37	29.51	101.43	17.54	22.80	22.59	44.94	13.97	68.28
Site Comparision Average Value				32.70	29.96	97.87	18.13	22.36	22.51	47.49	12.95	68.11
Average (%) difference from Site Comparision Average Value			5 Plus	1.00%	1.50%	-3.64%	3.27%	-1.95%	-0.35%	5.37%	-7.83%	-0.25%
			BSRIA	-1.00%	-1.50%	3.64%	-3.27%	1.95%	0.35%	-5.37%	7.83%	0.25%

Abbreviations

Avge	***Average mean value of all arguments***
Max	***Maximum value within data set***
Min	***Minimum value within data set***
Var	***Variance from the average mean across the data set***
SD	***Standard deviation from the average mean value across all arguments***
N/A	***Volunteer Not Available***

Table 56 - Research Site Temperature Related Measured Values.

5.6 Sensory Monitoring Vest Measurements.

The (x3) parameters measured by the sensory vest of breathing rate; heart rate and blood oxygen level are summarised within the following graphs Fig's 161-168 The sensory vest was worn by the research engineer due to issues with the volunteers not wishing to participate, and therefore the engineer was located within each respective area. As noted earlier the autumn period at BSRIA was not recorded.

Initial trials of the vest lead to some concern as to the accuracy and consistency of the blood oxygen monitoring given the relative steady state value measured and with little opportunity for increasing granularity (decimal places). Heart rate and breathing rate were more consistent in respect to values and consistency. However the R.E noted significant periods were the breathing rate became very shallow when concentrating on specific task, the vest providing an alarm when a low level-breathing rate had been achieved. This re-focussed the R.E to increase breathing rate and to sit up straight. The software provided a full ECG real time graphical trace to enable the R.E to observe, however the trace was very consistent real time and offered no real benefit. The data was transferred to xls and is presented in the following graphical figures.

The battery life of the vest caused some measuring issues. When using the blood oxygen finger probe the battery life of the vest was dramatically reduced to 2-3 hours. The presented data is therefore segmented into the periods the R.E was available and within the autonomy of a fully charged battery.

The sensory vest proofed a very difficult and unreliable means of measuring within an office environment despite the R.E wearing the vest. The sensory pads needed to remain moist and the blood oxygen ear lobe proved very difficult to retain in place. Consequently the amount data captured and available fro processing has been limited and is therefore presented as an indicative view of the measured parameters. The R.E would recommend an alternative sensory type is utilised in any further studies.

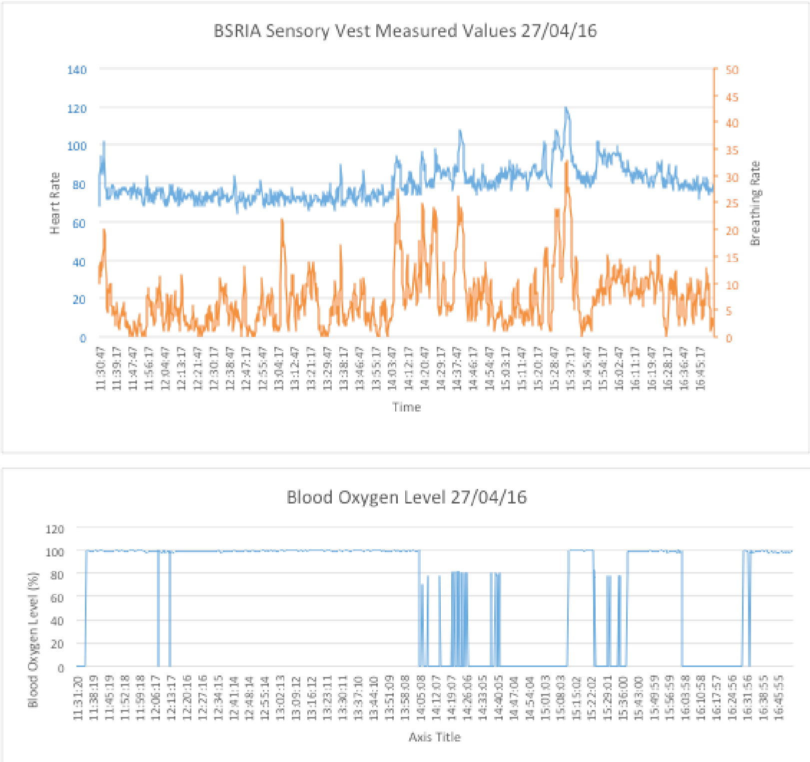


Fig. 161 - RE BSRIA Sensory Vest Data (Spring – 27/04/16)

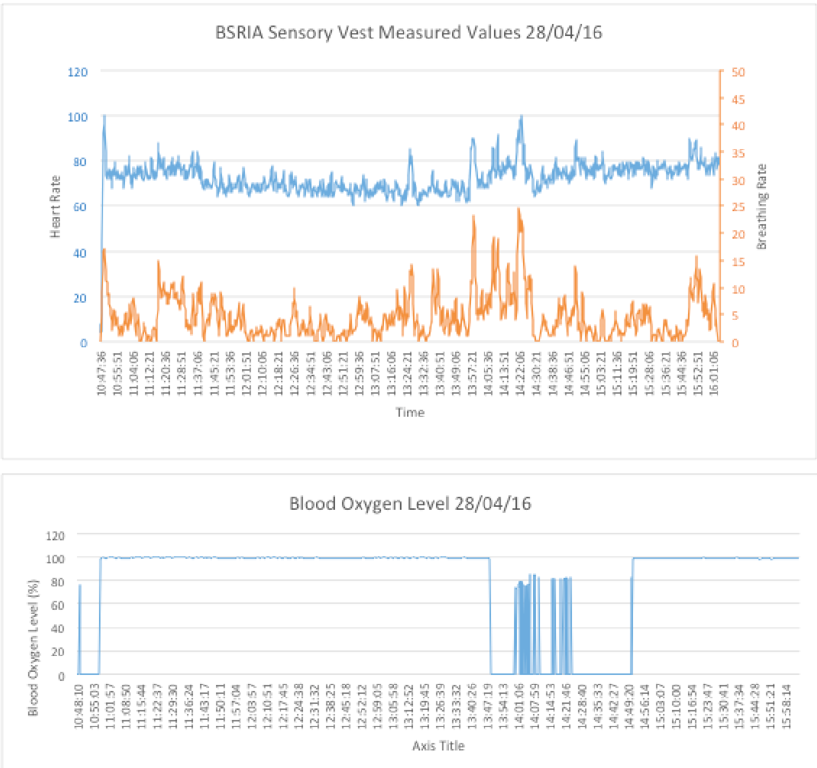


Fig. 162 - RE BSRIA Sensory Vest Data (Spring – 28/04/16)

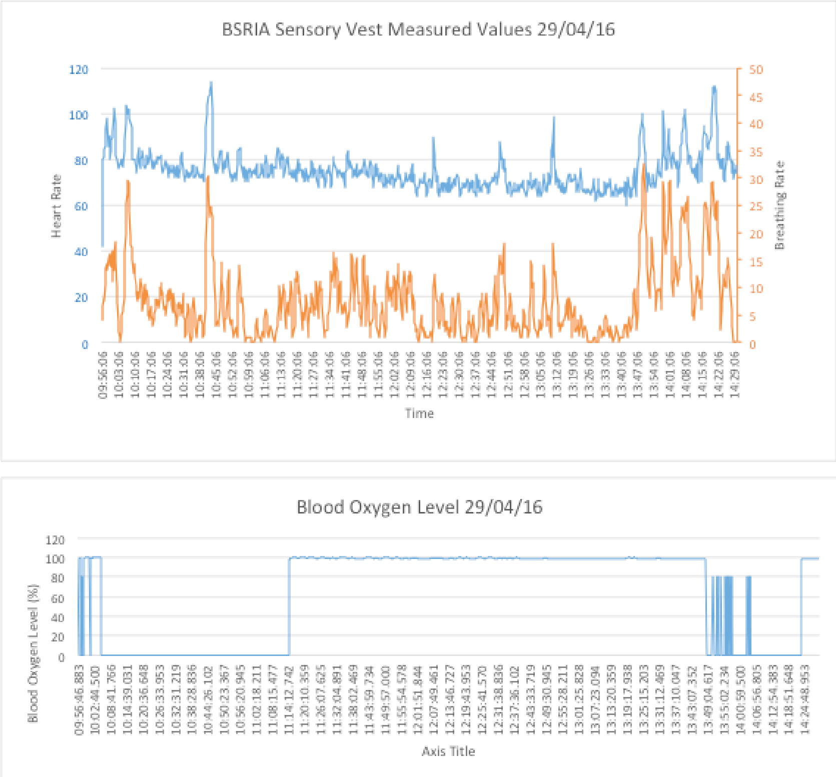


Fig. 163 - RE BSRIA Sensory Vest Data (Spring – 29/04/16)

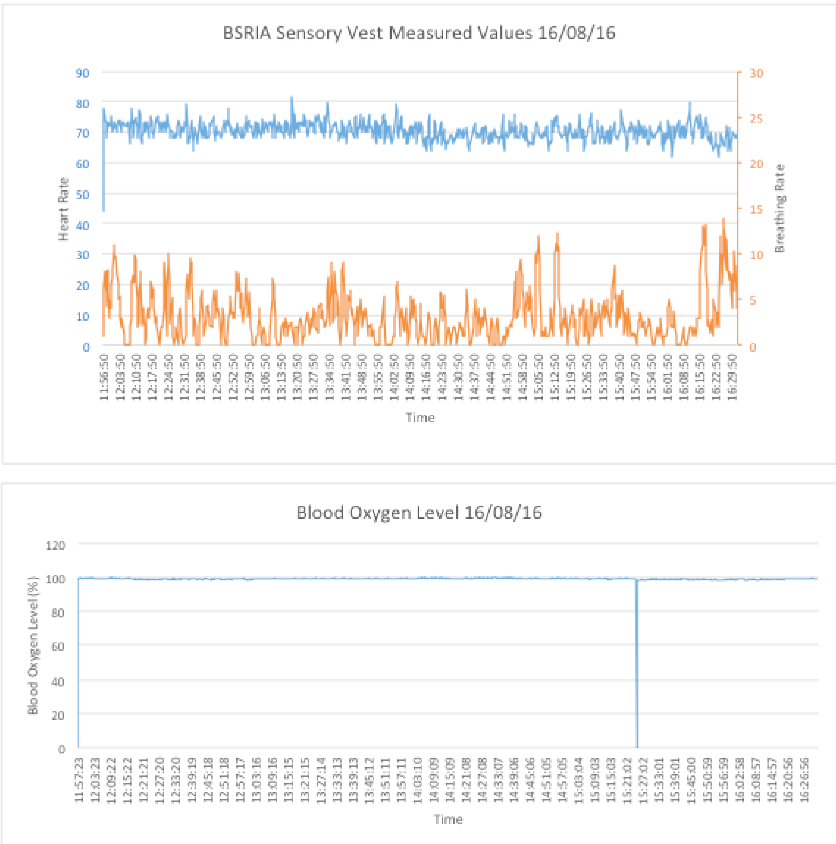


Fig. 164 - BSRIA Sensory Vest Data (Summer – 16/08/16)

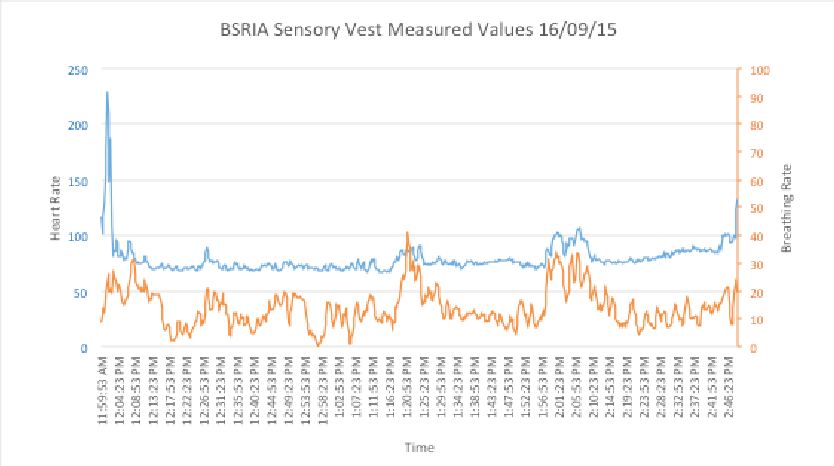


Fig. 165 - RE BSRIA Sensory Vest Data (Autumn – 16/09/15) – No Blood Oxygen Data Available

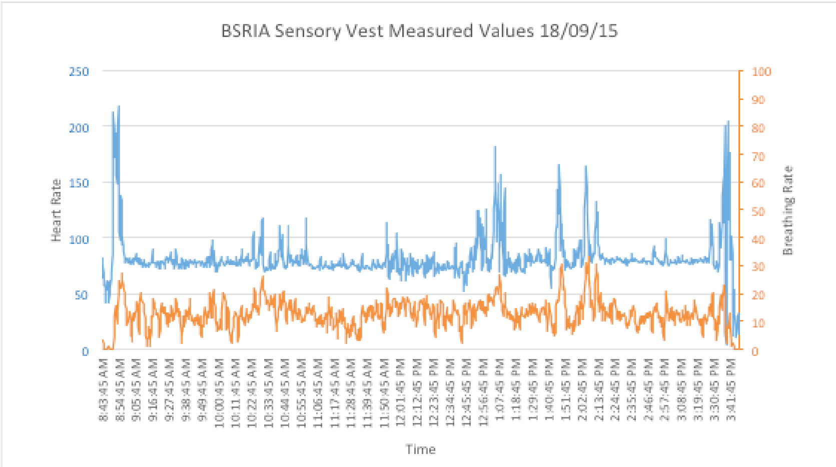


Fig. 166 - RE BSRIA Sensory Vest Data (Autumn – 18/09/15) – No Blood Oxygen Data Available

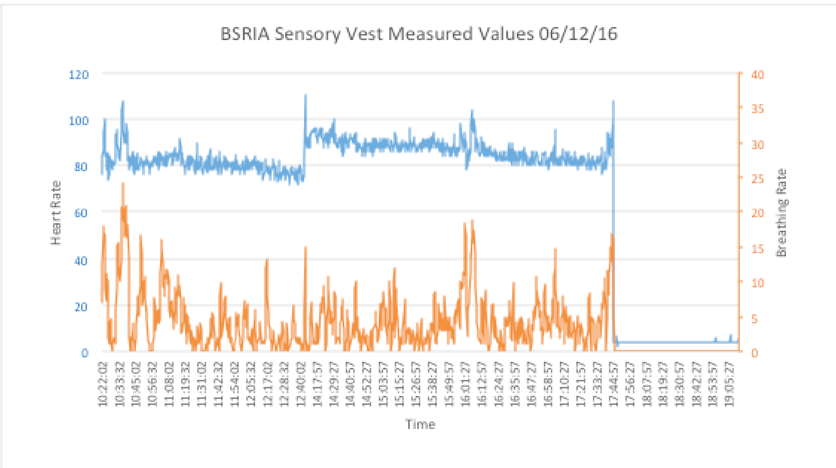


Fig. 167 - RE BSRIA Sensory Vest Data (Winter – 06/12/16) – No Blood Oxygen Data Available

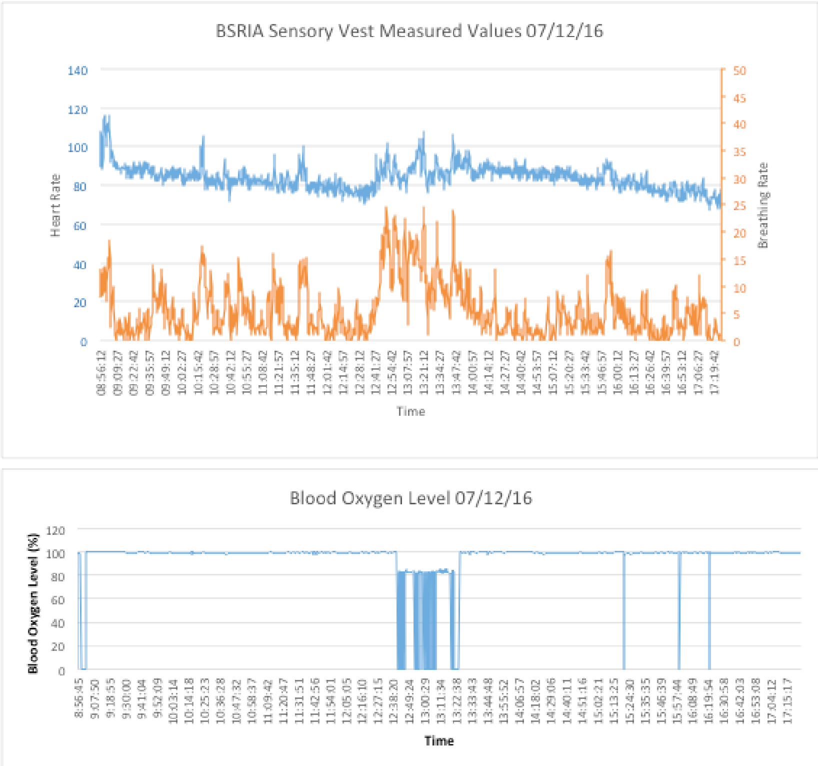


Fig. 168 - RE BSRIA Sensory Vest Data (Winter – 07/12/16)

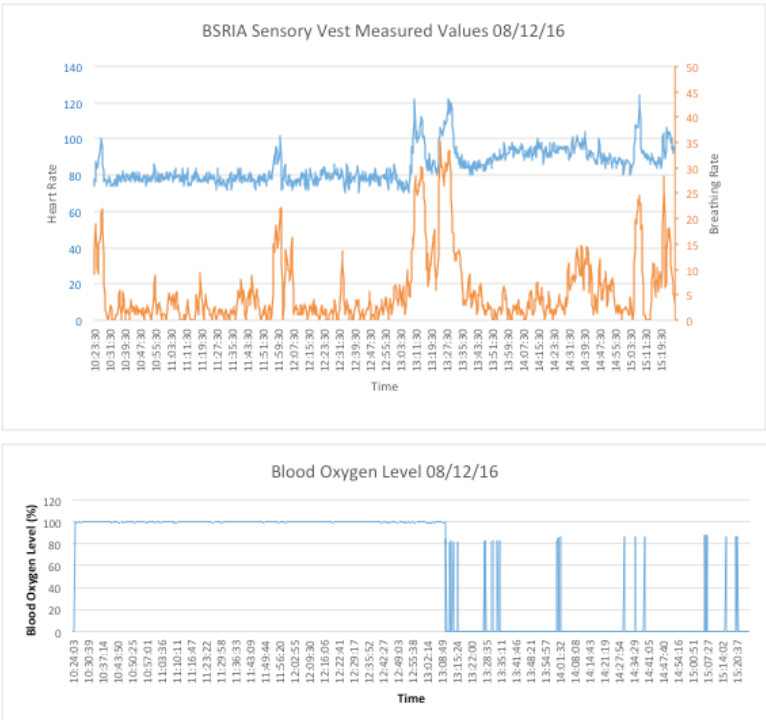


Fig. 169 - RE BSRIA Sensory Vest Data (Winter – 08/12/16)

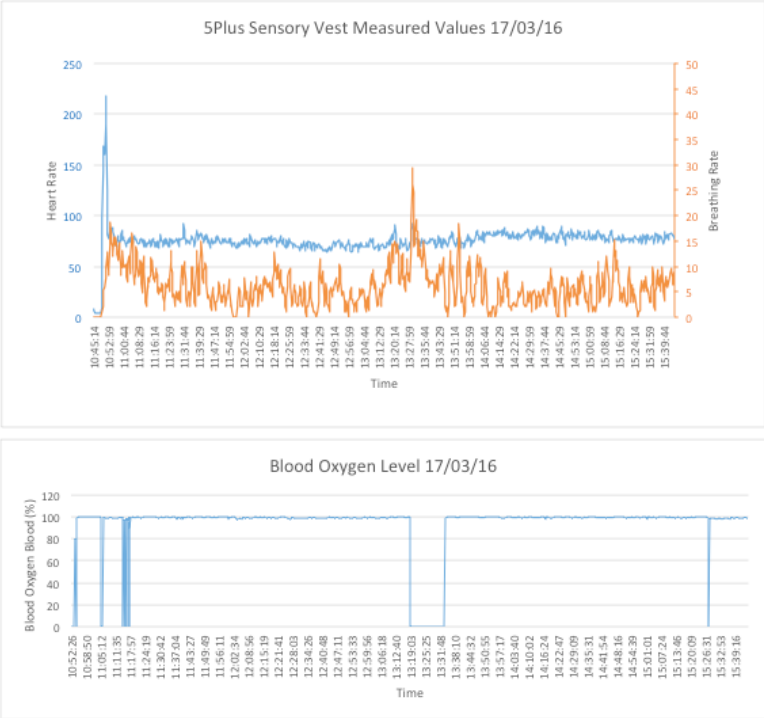


Fig. 170 - RE 5Plus Sensory Vest Data (Spring – 14/03/16)

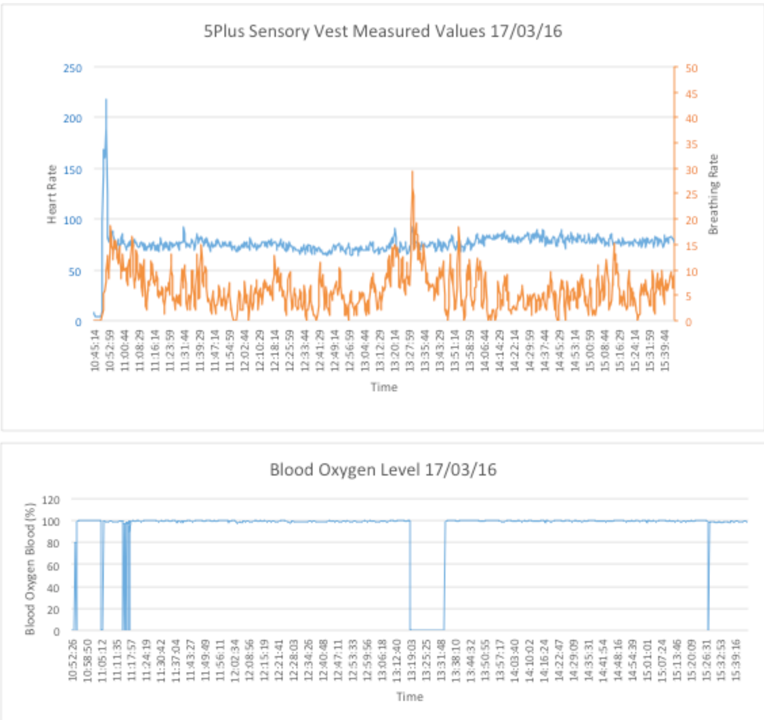


Fig. 171 - RE 5Plus Sensory Vest Data (Spring – 17/03/16)

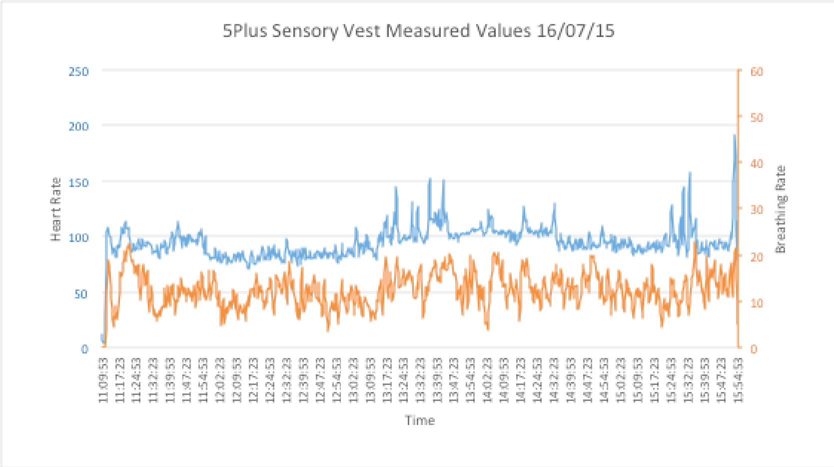


Fig. 172 - RE 5Plus Sensory Vest Data (Summer– 16/07/15) – No Blood Oxygen Data Available

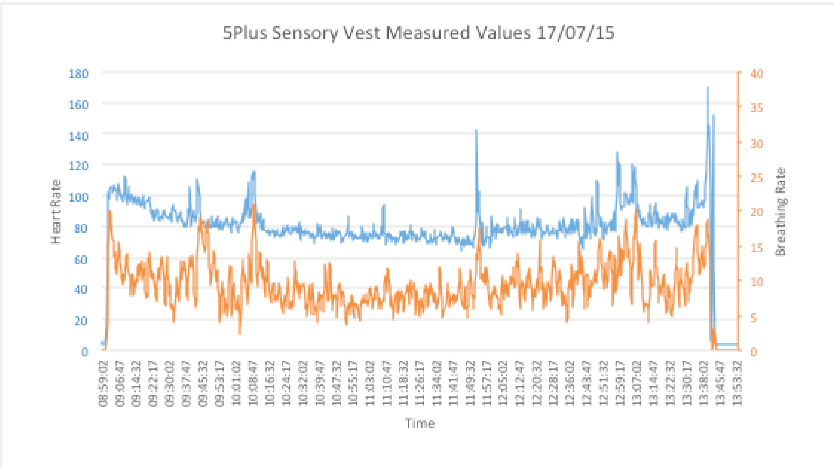


Fig. 173 - RE 5Plus Sensory Vest Data (Summer– 17/07/15) – No Blood Oxygen Data Available

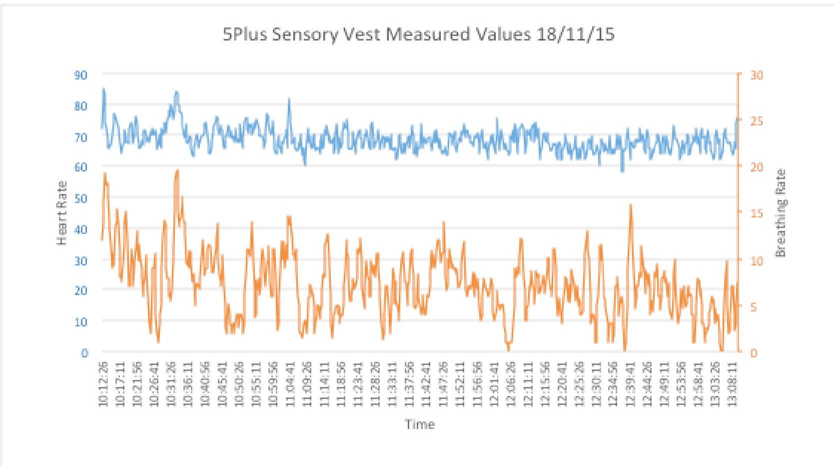


Fig. 174 - RE 5Plus Sensory Vest Data (Autumn – 18/11/15) – No Blood Oxygen Data Available

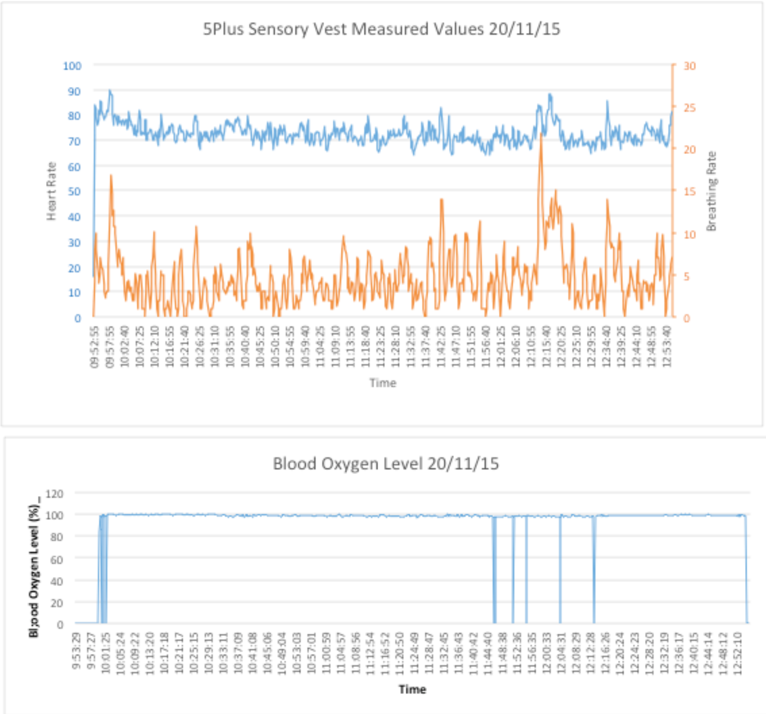


Fig. 175 - RE 5Plus Sensory Vest Data (Autumn – 20/11/15)

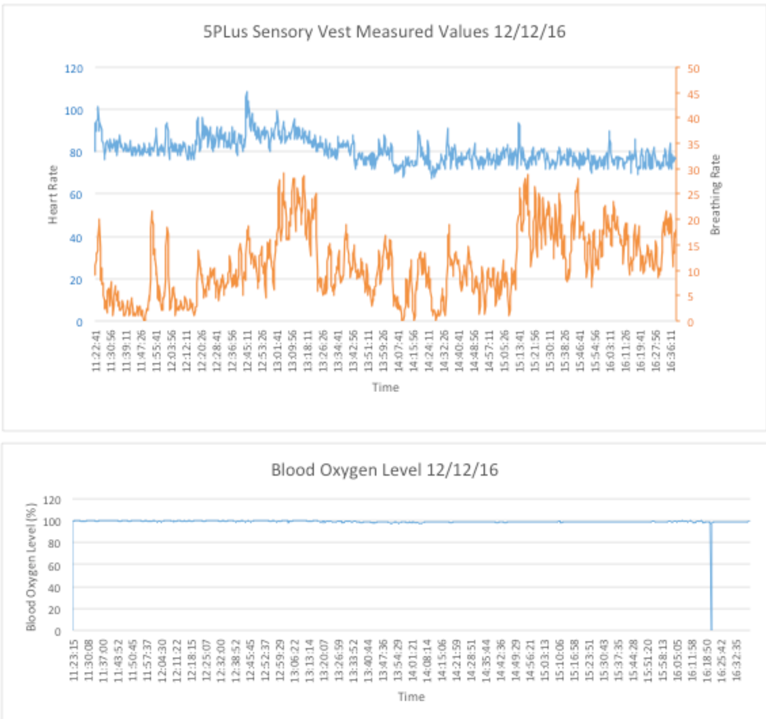


Fig. 176 - RE 5Plus Sensory Vest Data (Winter – 12/12/16)

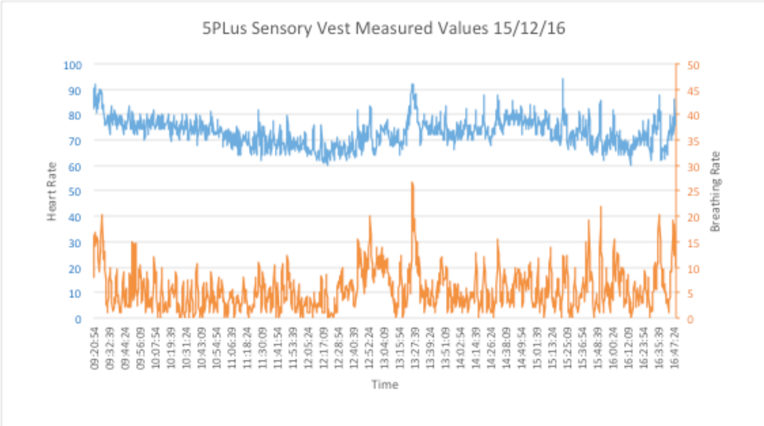


Fig. 177 - RE 5Plus Sensory Vest Data (Winter 15/12/16) – No Blood Oxygen Data Available

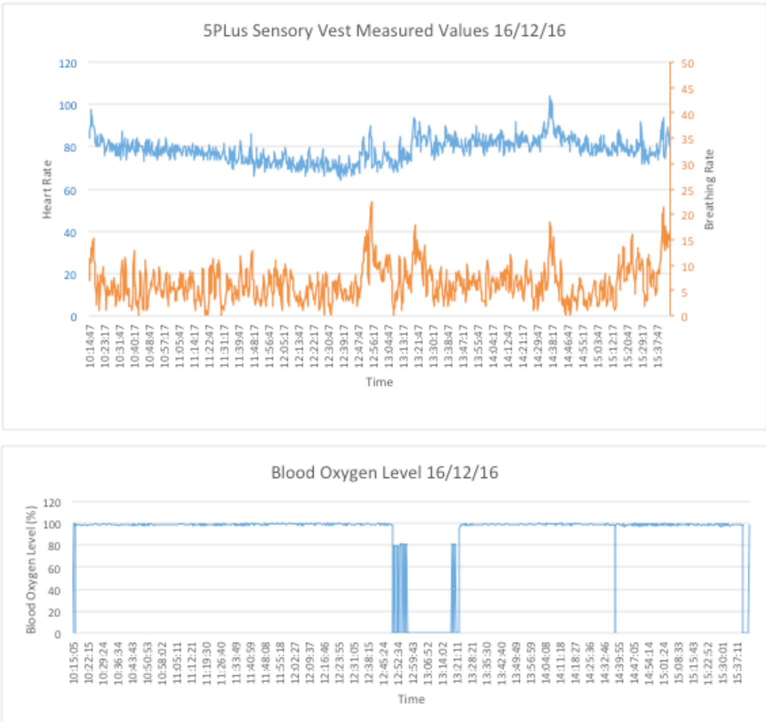


Fig. 178 - RE 5Plus Sensory Vest Data (Winter 16/12/16)

5.7 Chapter Summary

Previous physiological; studies tended to be based around chamber defined experiments (Fanger 1972; Zheng, Chen et al 2006 Li, Li et al 2010 each proposing skin temperature varies with changes in the ambient thermal environment. Chen & Hwang et al (2011) using further chamber studies, concluded approximately a <2deg.C increase in mean skin temperature when the ambient temperature changed by <4deg.C. Although these and many studies were conducted in ideal thermal chamber conditions there is very limited research associated with real time thermally unregulated environments such as naturally ventilated spaces.

Recent studies Liu (2012) – Occupant Adaptive Behaviour and Keeling (2016) – Parameters to Evaluate and Monitor IEQ, have utilised real workplaces to measure and analyse individual responses but not over such an extensive time period. The challenge of selecting suitable naturally ventilated sites and willing individuals was difficult, however, by selecting two organisations at the fore of progressive sustainable design was a key success factor. The daily, weekly and seasonal approach is considered to be a unique research approach however certain issues have been uncovered in this approach. These are detailed later in this section, however, using two disparate geographical UK sites has proven useful in establishing similar +/- response values.

Liu (2012) focussed upon the thermal responses with respect to clothing level, concluding both clothing level and activity measured by metabolic exchange (MET) affected GSR value. Liu discovered a seasonal change in GSR similar to the seasonal values measured during this research, however, Liu observed the seasonal changes during the warmer periods to be relative, while the colder transitional seasons being relative to each other with significant changes in value between warmer and transitionary cooler periods.

This chapter is interested in understanding the fundamental issue of monitoring the human physiological responses within occupied work environments, and to understand how the data may be interpreted for use with future building feedback system. The future adoption of such real-time empirical performance related information being relative and useful to connecting the individual to the built environment intelligently as a bi-directional feedback system. The affects of the built environment are experienced through the senses and controlled via the brain, therefore being within a real time work environment all the senses (Clements-Croome 2007) can be said to be contributory to the measured values.

The measured values would indicate as concluded by Yun and Steemers (2008) and Chen and Hwang et al (2011), that occupant behaviour and physiological responses are time-dependant. Where the occupant experiences a thermal transition, the response is noted in changes to skin or near body temperature that are opposite changes in heat flux average. GSR values and response would also support a time-dependant correlation particular at the start and end of the day. GSR values generally appeared at both sites daily and weekly to follow a downward trend Monday to Friday, however, with certain exceptions but the RE understands this in the main to be work related. GSR profiling would suggest that daily profiles could be considered similar for each individual with opportunities to utilise historical GSR values in assessing future periods were higher “stressor” GSR values may be experienced. To a certain extent this can be considered subjective given work related tasks and stress are psychological unknowns, however Chapter 6 considers the correlation of each physiological value to the ambient conditions.

Table 56 summarises the research values and provides evidence similar to Liu (2012) that seasonal relevance for skin temperature average values across all volunteers at BSRIA were extremely close, with only 0.7deg.C difference across each individual and season. 5Plus average values were slightly more at 3.51deg.C however, the average value between sites concludes only a +/-1% difference between sites. Similarly near body temperature was very consistent in values with only +/- 1.5% average difference between sites. Variance and SD values were considered acceptable levels of deviation.

Heat Flux average was considered to be a more transitional metric given the large variance, however SD was considered acceptable. The large variance would suggest this is not an ideal variable to assess performance as other local factors e.g. clothing, fans; draughts could significantly affect the value. Interestingly the difference in average values between sites +/- 3.64% would support some further limited review of this parameter.

GSR values were extremely low and required scientific notation to assess their real value. As a key stressor and variable parameter, GSR is perhaps the most interesting time-dependant parameter to view. The measured results for (x3) males at 5Plus indicated very similar GSR values including relative energy expended (KJ) values. The (x1) measured female values at 5Plus indicated a x4 increase in GSR value despite reduced energy expended values.

The (x1) male measured values at BSRIA indicated very similar values to the (x3) male volunteers at 5Plus, however only (x2) female volunteers indicated similar values to those noted across (x1) female volunteer at 5Plus. Energy expended and Metabolic Equivalent values also remained very similar. There would therefore appear to be certain discreet GSR value differences between female and male occupants in similar orders of magnitude for similar types of space. The % average difference between sites remains consistent and of small value as with other measured values; GSR +/- 1.64%; EE +/- 2.87%; MET +/- 1.43%.

The main findings and observations of this chapter are noted as follows:

1. GSR would appear to be time dependant around certain periods of the day and indicate continuous sharp increases and decreases consistently throughout the day.
2. GSR values rise sharply at the start of the day and follow simple profiles for each volunteer subject to periods of work related or time dependent events.
3. The large majority of GSR trends indicate a downward trend from Mon-Fri.
4. GSR profiles of individuals at both sites can be considered similar.
5. A discrete difference in GSR value exists between male & female volunteers.
6. Skin and near body temperature are closely related due to sensor location.
7. Skin temperature rises constantly during the day around the expected value of approx. 24deg.c despite daily and seasonal temperature differences.
8. Skin and near body temperature changes appear to be environmental dependant and not time dependant and achieve an opposite reaction in Heat Flux average during transient response to change.
9. Heat flux average is not suitable as a measuring parameter due to method of calculation and measurement, and location of the sensor.
10. A seasonal consistency exists across all measured average values.
11. Arrival, occupancy and departure phases do appear to have relative affect upon measured values, but this could be due to device normalisation.
12. Within what was considered to be a relatively stable internal environment there is no discrete evidence to suggest transitional seasonal changes exists across any of the measured values.
13. The two sites provided similar average values and performance within reasonable tolerances, this could be developed and used within building feedback system using predictive artificial intelligence.
14. Breathing rate and heart rate provides limited conclusive output.

15. Blood oxygen monitoring is not considered a suitable or robust measured parameter due to difficulty in measuring through available devices. Accuracy is also not vey good due to sensor technology and wear ability issues.
16. It is difficult to assess the causation of transient events due to work task or emotional stress, and therefore the empirically measured data can only be considered as time specific within a real life operational situation.
17. The armband technology would appear a more robust method of measuring the necessary parameters in comparison to the limited sensory vest.
18. The use of volunteers proved difficult to motivate, and therefore some form of wider study may help in establishing additional data.
19. The use of the sensory vest proved exceedingly difficult due to battery life and wear ability. Female participation was rejected and male use proved uncomfortable within a sedentary daily work environment over a period of hours. Using the R.E as a sensory vest wearer was not ideal due to location within the research space.
20. Effects of clothing did not form part of this study as they have covered in previous work, but there is an acceptance that certain extraneous elements are relative to this research.

Although significant amounts of data has been collected and analysed, consideration should be given to extend such a study and to consider additional sites with more individuals. The consistency of results within similar site ambient environments, would suggest additional review would be useful in confirming the validity of this research.

Chapter 6 – IEQ Monitoring

6.1 Introduction

The environmental data was measured at (x5) positions across both workplaces at BSRIA and 5 Plus Architects located in Bracknell and Manchester respectively. Both sites are naturally ventilated environments meaning the ambient control is only minimally controlled via manual or semi-automated means either by opening of windows/vents and/or heating TRV radiator valves.

Recognising the various survey outputs, the environmental data has been categorised towards thermal conditions, IAQ (CO_2) and Noise, to assess if the physiological responses of skin temperature and GSR are able to correlate. The physiological data gathered from the sensory vest is not considered robust enough to utilise as a correlation data set and has therefore not been utilised.

The use of Pearson's (r) and a review of regression significance (*p*<) has been utilised to undertake a correlation assessment between the various independent variables detailed within Fig's. 179-192 (BSRIA) and Figs. 187-190 (5Plus) The data has been short formed to cover two individuals and Table 61 consolidates the statistical review across (x2) volunteers seasonally; (x1) CH from 5Plus and (x1) MA-H from BSRIA.

6.2 Environmental Data Review

The ambient data was measured during the day & night-time to assess the differences in building performance with occupants present and when absent. This was specifically designed to assess background levels for each independent variable and the following figures provide a seasonal perspective across both sites. Both office spaces were allowed to run free in terms of measuring an occupied working space and therefore data may or may not be affected by extraneous influences. The intent of the research is to consider real time events, but not to be specific at this stage in terms of actual event causation. As a real-time environment, we are concerned at reviewing the data as it occurs and to understand how the space preforms within expected design norms. Tables 58 & 59 (5 Plus) & Tables 60 & 61 provide a view of the seasonal ambient internal & external temperature conditions confirming both spaces performed as expected and as designed.

Hand-held Internal/Extrenal Ambient Measurements

Date	12-16/12/2016							
	Internal						External	
	Time	Occupancy	WBGT °C	Air Temperature °C	Globe Temperature °C	Humidity %RH	Air Temperature °C	Humidity %RH
Mon 12/12/16	09:00	16	15.9	20.8	21.6	40.7	4.8	78.5
	11:00	30	16.2	20.9	21.6	41.8	6.2	76.9
	13:00	25	16.7	21.6	22.0	54.6	9.4	68.9
	15:00	29	17.4	21.9	22.4	60.4	11.0	67.4
	17:00	28	17.1	22.1	22.7	57.4	10.3	70.0
	Average Value	**26**	**16.7**	**21.5**	**22.1**	**51.0**	**8.3**	**72.3**
Tues 13/12/16	09:00	No site readings due to Research Engineer Unavailable						
	11:00							
	13:00							
	15:00							
	17:00							
	Average Value	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Wed 14/12/16	09:00	24	16.8	21.9	22.3	48.3	8.5	59.9
	11:00	24	16.7	22.0	22.6	51.4	9.3	60.7
	13:00	26	16.1	22.1	22.9	49.0	9.6	60.4
	15:00	18	15.9	21.9	22.4	41.9	8.9	64.8
	17:00	20	16.4	22.6	22.7	35.8	8.7	60.6
	Average Value	**22**	**16.4**	**22.1**	**22.6**	**45.3**	**9.0**	**61.3**
Thurs 15/12/16	09:00	20	16.5	22.1	22.2	40.1	8.4	80.1
	11:00	23	17.2	22.8	22.8	41.2	10.4	84.3
	13:00	22	17.2	22.9	22.8	43.8	10.8	86.4
	15:00	27	17.7	22.5	22.6	44.1	10.9	87.9
	17:00	24	17.2	22.4	22.3	43.2	11.6	80.7
	Average Value	**23**	**17.2**	**22.5**	**22.5**	**42.5**	**10.4**	**83.9**
Fri 16/12/16	09:00	20	15.7	20.0	20.1	46.3	12.8	75.9
	11:00	22	16.1	20.4	20.4	49.4	13.4	79.3
	13:00	23	16.3	21.9	21.9	40.3	13.9	80.7
	15:00	24	16.9	22.2	22.2	41.8	13.9	78.9
	17:00	20	17.1	22.5	22.5	41.8	12.6	80.4
	Average Value	**22**	**16.4**	**21.4**	**21.4**	**43.9**	**13.3**	**79.0**
Seasonal Average Value		**23**	**16.7**	**21.9**	**22.2**	**45.7**	**10.3**	**74.1**

Hand-held Internal/External Ambient Measurements

Date	16-20/11/15							
	Internal						External	
	Time	Occupancy	WBGT °C	Air Temperature °C	Globe Temperature °C	Humidity %RH	Air Temperature °C	Humidity %RH
Mon 16/11/15	09:00	13	18.5	21.8	21.5	65.4	10.8	71.4
	11:00	21	18.4	21.3	21.7	63.3	11.4	70.8
	13:00	20	18.6	22.6	22.8	66.1	11.3	76.4
	15:00	18	18.6	22.0	22.9	65.2	9.8	74.7
	17:00	24	18.9	22.5	22.7	68.7	9.7	76.2
	Average Value	**19**	**18.6**	**22.0**	**22.3**	**65.7**	**10.6**	**73.9**
Tues 17/11/15	09:00	10	16.8	21.9	21.5	55.1	8.5	80.6
	11:00	18	17.5	22.2	21.8	50.7	10.3	82.3
	13:00	21	17.7	22.4	22.7	52.5	11.4	83.7
	15:00	24	18.4	22.7	22.8	53.9	13.6	87.1
	17:00	20	18.7	23.4	22.7	56.7	13.2	78.6
	Average Value	**19**	**17.8**	**22.5**	**22.3**	**53.8**	**11.4**	**82.5**
Wed 18/11/15	09:00	8	15.9	18.9	19.6	48.2	11.7	70.2
	11:00	17	16.8	19.5	19.9	49.8	13.3	67.9
	13:00	21	17.0	19.7	20.4	53.8	12.8	68.1
	15:00	24	17.2	20.6	21.9	54.5	12.9	72.6
	17:00	23	17.7	21.2	21.9	50.7	11.8	73.0
	Average Value	**19**	**16.9**	**20.0**	**20.7**	**51.4**	**12.5**	**70.4**
Thurs 19/11/15	09:00	15	17.2	22.1	21.5	63.7	9.0	70.6
	11:00	20	17.6	22.0	22.3	61.5	10.4	69.4
	13:00	22	18.3	21.8	22.1	59.6	10.6	67.8
	15:00	24	18.7	24.0	24.8	47.4	9.1	65.9
	17:00	26	18.6	24.3	24.9	51.8	8.0	67.4
	Average Value	**21**	**18.1**	**22.8**	**23.1**	**56.8**	**9.4**	**68.2**
Fri 20/11/15	09:00	8	15.9	19.6	21.2	48.6	6.9	80.1
	11:00	16	16.7	20.8	21.6	51.1	7.4	78.3
	13:00	20	17.1	22.1	22.1	48.7	7.6	76.7
	15:00	22	17.6	22.7	22.8	57.6	7.9	82.3
	17:00	22	17.5	22.7	22.8	54.3	5.7	84.7
	Average Value	**18**	**17.0**	**21.6**	**22.1**	**52.1**	**7.1**	**80.4**
Seasonal Average Value		**19**	**17.7**	**21.8**	**22.1**	**56.0**	**10.2**	**75.1**

Table 58 - 5Plus Environmental Ambient Data Overview (Handheld Measurements (Winter & Autumn)

Hand-held Internal/Extrenal Ambient Measurements

Date	13-17/07/15							
	Internal						External	
	Time	Occupancy	WBGT °C	Air Temperature °C	Globe Temperature °C	Humidity %RH	Air Temperature °C	Humidity %RH
Mon 13/07/15	09:00	11	18.1	22.1	23.8	52.6	15.7	58.7
	11:00	27	18.4	23.0	24.1	57.1	15.9	60.2
	13:00	27	19.6	23.8	24.6	59.3	18.2	61.5
	15:00	20	20.2	23.4	24.1	61.8	18.5	72.4
	17:00	22	20.8	23.7	24.6	58.9	17.6	65.9
	Average Value	**21**	**19.4**	**23.2**	**24.2**	**57.9**	**17.2**	**63.7**
Tues 14/07/15	09:00	16	18.4	22.6	23.1	56.7	15.4	73.6
	11:00	26	18.5	22.9	23.3	52.7	16.3	71.7
	13:00	25	18.9	23.8	24.2	49.6	17.4	54.7
	15:00	21	18.4	24.1	24.4	43.5	18.5	56.3
	17:00	20	18.1	24.4	25.1	50.1	19.0	68.5
	Average Value	**22**	**18.5**	**23.6**	**24.0**	**50.5**	**17.3**	**65.0**
Wed 15/07/15	09:00	16	15.4	20.7	22.0	37.1	15.6	56.3
	11:00	26	16.1	21.6	22.5	38.3	15.7	54.7
	13:00	26	16.7	23.3	23.1	35.8	26.5	58.2
	15:00	23	17.3	24.2	24.2	32.9	17.3	52.1
	17:00	24	17.6	25.0	24.8	41.7	17.1	59.4
	Average Value	**23**	**16.6**	**23.0**	**23.3**	**37.2**	**18.4**	**56.1**
Thurs 16/07/15	09:00	16	16.8	22.2	22.6	41.7	16.4	60.7
	11:00	15	17.1	22.7	22.8	43.3	19.1	63.5
	13:00	12	17.5	23.2	23.3	41.5	21.3	59.8
	15:00	13	18.6	24.2	24.6	42.5	20.8	53.2
	17:00	10	19.2	24.9	25.3	40.6	22.6	56.4
	Average Value	**13**	**17.8**	**23.4**	**23.7**	**41.9**	**20.0**	**58.7**
Fri 17/07/15	09:00	12	18.4	22.3	23.1	55.0	19.1	59.9
	11:00	26	18.1	22.6	22.7	50.8	19.8	58.7
	13:00	23	17.5	22.4	22.9	47.3	18.9	54.8
	15:00	25	16.9	23.6	23.9	34.7	18.7	49.8
	17:00	24	17.5	24.4	24.9	40.4	19.4	48/7
	Average Value	**22**	**17.7**	**23.1**	**23.5**	**45.6**	**19.2**	**55.8**
Seasonal Average Value		**20**	**18.0**	**23.2**	**23.8**	**46.6**	**18.4**	**60.0**

Hand-held Internal/Extrenal Ambient Measurements

Date	14-18/03/16							
	Internal						External	
	Time	Occupancy	WBGT °C	Air Temperature °C	Globe Temperature °C	Humidity %RH	Air Temperature °C	Humidity %RH
Mon 14/03/16	09:00	21	16.8	19.4	19.7	49.8	6.7	54.7
	11:00	25	17.4	20.1	20.3	52.1	9.1	59.5
	13:00	26	17.9	20.2	20.5	52.9	11.4	58.7
	15:00	19	18.2	20.9	21.2	50.6	12.3	58.2
	17:00	22	18.2	20.8	21.3	51.0	11.0	57.1
	Average Value	**23**	**17.7**	**20.3**	**20.6**	**51.3**	**10.1**	**57.6**
Tues 15/03/16	09:00	19	17.1	20.1	21.5	47.6	8.3	60.5
	11:00	21	17.8	20.7	21.7	49.8	7.9	65.4
	13:00	22	18.4	21.1	22.6	50.5	9.4	64.8
	15:00	25	18.9	22.0	22.9	52.1	10.4	63.4
	17:00	26	19.0	22.1	22.9	53.3	9.8	70.1
	Average Value	**23**	**18.2**	**21.2**	**22.3**	**50.7**	**9.2**	**64.8**
Wed 16/03/16	09:00	24	17.6	20.6	21.5	48.0	6.0	58.7
	11:00	24	17.9	20.7	21.3	52.6	9.2	60.1
	13:00	26	18.8	21.3	22.7	57.4	10.3	64.6
	15:00	18	18.2	21.2	22.7	56.5	11.6	67.8
	17:00	20	18.2	21.0	22.4	52.6	9.0	63.4
	Average Value	**22**	**18.1**	**21.0**	**22.1**	**53.4**	**9.2**	**62.9**
Thurs 17/03/16	09:00	20	17.1	19.8	20.8	49.7	6.7	60.2
	11:00	23	17.6	19.7	20.5	51.0	7.5	60.9
	13:00	22	17.8	20.6	21.9	51.9	9.1	63.2
	15:00	27	18.1	21.2	22.7	54.8	11.3	59.9
	17:00	24	18.0	21.3	22.2	52.7	9.7	58.7
	Average Value	**23**	**17.7**	**20.5**	**21.6**	**52.0**	**8.9**	**60.6**
Fri 18/03/16	09:00	20	17.6	20.4	21.1	50.3	5.8	64.6
	11:00	22	17.8	20.4	21.2	50.6	6.7	67.8
	13:00	23	18.2	21.6	22.5	51.7	7.6	68.4
	15:00	24	18.4	21.8	22.6	55.6	7.5	66.7
	17:00	20	18.2	21.0	22.0	52.1	7.1	65.8
	Average Value	**22**	**18.0**	**21.0**	**21.9**	**52.1**	**6.9**	**66.7**
Seasonal Average Value		**23**	**18.0**	**20.8**	**21.7**	**51.9**	**8.9**	**62.5**

Table 59 - 5Plus Environmental Ambient Data Overview (Handheld Measurements (Summer & Spring)

Hand-held Internal/External Ambient Measurements

Date	05-08/12/16							
	Internal						External	
	Time	Occupancy	WBGT °C	Air Temperature °C	Globe Temperature °C	Humidity %RH	Air Temperature °C	Humidity %RH
Mon 05/12/16	09:00	10	16.9	21.8	22.1	45.0	-2.0	67.8
	11:00	8	17.1	22.4	22.6	43.3	4.0	70.1
	13:00	11	17.4	22.6	22.9	46.7	7.6	74.7
	15:00	12	17.3	22.5	22.8	45.8	4.7	69.8
	17:00	6	16.3	21.2	20.8	48.5	1.9	68.7
	Average Value	**9**	**17.0**	**22.1**	**22.2**	**45.9**	**3.2**	**70.2**
Tues 06/12/16	09:00	10	16.8	21.9	22.0	46.7	5.4	87.4
	11:00	12	17.2	22.3	22.2	44.0	7.2	89.5
	13:00	6	18.2	22.8	22.6	50.7	8.3	92.7
	15:00	10	18.1	23.1	23.1	45.8	9.1	87.4
	17:00	8	17.2	22.1	21.9	51.9	8.5	83.6
	Average Value	**9**	**17.5**	**22.4**	**22.4**	**47.8**	**7.7**	**88.1**
Wed 07/12/16	09:00	11	17.9	23.0	22.9	50.3	11.4	80.4
	11:00	10	18.8	23.9	23.8	48.8	12.7	78.5
	13:00	8	18.6	23.4	23.5	51.4	12.8	79.5
	15:00	10	18.9	23.9	23.8	50.3	12.7	82.7
	17:00	12	18.7	23.4	23.3	52.1	11.0	85.8
	Average Value	**10**	**18.6**	**23.5**	**23.5**	**50.6**	**12.1**	**81.4**
Thurs 08/12/16	09:00	14	14.5	19.6	19.8	39.4	12.4	88.4
	11:00	12	15.9	21.9	21.8	41.5	13.2	89.5
	13:00	15	16.1	22.4	22.2	35.3	12.8	90.4
	15:00	2	16.9	22.8	23.1	36.6	11.8	92.0
	17:00	N/A	N/A	N/A	N/A	N/A	12.7	86.6
	Average Value	**11**	**15.9**	**21.7**	**21.7**	**38.2**	**12.6**	**89.4**
Fri 09/12/16	09:00	**No site reading due to Office Closing**						
	11:00							
	13:00							
	15:00							
	17:00							
	Average Value	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Seasonal Average Value		**10**	**17.3**	**22.5**	**22.5**	**46.0**	**8.9**	**82.3**

Hand-held Internal/External Ambient Measurements

Date	14-18/09/15							
	Internal						External	
	Time	Occupancy	WBGT °C	Air Temperature °C	Globe Temperature °C	Humidity %RH	Air Temperature °C	Humidity %RH
Mon 14/09/15	09:00	10	16.9	20.2	20.4	40.5	15.0	69.6
	11:00	12	17.8	21.6	21.9	46.7	17.4	71.7
	13:00	8	17.4	21.7	22.0	44.4	17.8	72.8
	15:00	10	17.8	22.3	22.5	49.6	16.3	70.4
	17:00	10	17.8	22.0	22.7	47.2	15.9	67.8
	Average Value	**10**	**17.5**	**21.6**	**21.9**	**45.7**	**16.5**	**70.5**
Tues 15/09/15	09:00	6	16.1	19.8	20.0	44.6	14.9	70.5
	11:00	10	16.8	20.7	21.1	48.3	17.0	74.6
	13:00	12	17.2	21.4	22.1	51.2	18.3	78.5
	15:00	7	16.9	21.0	21.8	50.7	16.8	67.9
	17:00	9	17.0	21.2	21.9	49.6	16.4	67.1
	Average Value	**9**	**16.8**	**20.8**	**21.4**	**48.9**	**16.7**	**71.7**
Wed 16/09/15	09:00	10	17.6	20.8	21.7	50.4	14.6	67.2
	11:00	12	17.8	20.7	21.9	56.7	15.6	60.8
	13:00	6	18.6	21.6	22.4	59.4	15.9	67.8
	15:00	8	19.7	21.9	22.9	53.6	16.7	65.3
	17:00	8	19.4	22.0	23.1	55.2	16.8	64.6
	Average Value	**9**	**18.6**	**21.4**	**22.4**	**55.1**	**15.9**	**65.1**
Thurs 17/09/15	09:00	4	16.7	19.6	20.0	49.8	13.6	68.3
	11:00	6	16.9	21.2	21.8	54.3	14.0	70.3
	13:00	10	17.8	22.1	22.7	60.4	14.8	70.2
	15:00	12	18.3	23.0	23.5	63.9	15.6	74.7
	17:00	8	17.9	23.0	23.8	59.6	15.4	73..2
	Average Value	**8**	**17.5**	**21.8**	**22.4**	**57.6**	**14.7**	**70.9**
Fri 18/09/15	09:00	6	16.8	20.6	20.9	50.7	13.9	65.0
	11:00	12	17.4	21.7	22.0	57.4	14.1	68.7
	13:00	10	17.8	22.0	2.6	56.2	15.6	66.5
	15:00	6	18.5	22.8	23.2	54.8	16.3	62.3
	17:00	4	17.9	22.1	22.7	50.1	16.0	60.1
	Average Value	**8**	**17.7**	**21.8**	**18.3**	**53.8**	**15.2**	**64.5**
Seasonal Average Value		**9**	**17.6**	**21.5**	**21.3**	**52.2**	**15.8**	**68.4**

Table 60 - BSRIA Environmental Ambient Data Overview (Handheld Measurements (Winter & Autumn)

Hand-held Internal/External Ambient Measurements

Date	Time	Occupancy	WBGT °C	Air Temperature °C (Internal)	Globe Temperature °C (Internal)	Humidity %RH (Internal)	Air Temperature °C (External)	Humidity %RH (External)
	15-19/08/16							
	Internal						External	
Mon 15/08/16	09:00	12	17.8	22.9	22.7	40.1	18.8	76.9
	11:00	10	18.7	24.8	24.8	41.4	20.1	82.3
	13:00	8	18.9	24.9	24.9	39.2	22.4	84.5
	15:00	12	18.7	25.1	24.9	40.1	23.6	74.3
	17:00	8	18.8	25.1	24.8	40.5	22.1	67.5
	Average Value	**10**	**18.6**	**24.6**	**24.4**	**40.3**	**21.4**	**77.1**
Tues 16/08/16	09:00	9	18.9	23.7	23.6	51.6	18.5	64.0
	11:00	10	20.2	35.3	25.1	50.3	20.6	58.9
	13:00	10	20.2	26.0	26.0	44.7	22.8	49.8
	15:00	8	20.0	26.4	26.3	42.6	23.4	47.6
	17:00	11	20.5	26.8	26.7	41.2	23.1	45.9
	Average Value	**10**	**20.0**	**27.6**	**25.5**	**46.1**	**21.7**	**53.2**
Wed 17/08/16	09:00	**No site reading due to Research Engineer unavailable**						
	11:00							
	13:00							
	15:00							
	17:00							
	Average Value	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
Thurs 18/08/16	09:00	13	18.1	22.7	22.2	43.7	19.4	60.1
	11:00	15	19.8	24.3	24.6	51.4	19.9	67.4
	13:00	4	20.6	26.1	26.3	46.2	22.4	54.9
	15:00	13	20.1	26.4	26.3	39.6	23.8	53.6
	17:00	12	20.4	27.1	27.3	38.0	23.6	48.7
	Average Value	**11**	**19.8**	**25.3**	**25.3**	**43.8**	**21.8**	**56.9**
Fri 219/08/16	09:00	8	20.4	23.7	23.5	49.7	17.9	88.3
	11:00	9	21.2	25.6	25.6	56.0	18.6	87.4
	13:00	6	21.3	25.8	25.6	56.5	18.9	90.2
	15:00	5	21.1	25.3	25.5	53.4	19.6	89.6
	17:00	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Average Value	**7**	**21.0**	**25.1**	**25.1**	**53.9**	**18.8**	**88.9**
Seasonal Average Value		**10**	**19.8**	**25.7**	**25.1**	**45.6**	**21.0**	**68.0**

Hand-held Internal/External Ambient Measurements

Date	Time	Occupancy	WBGT °C	Air Temperature °C (Internal)	Globe Temperature °C (Internal)	Humidity %RH (Internal)	Air Temperature °C (External)	Humidity %RH (External)
	25-29/04/16							
	Internal						External	
Mon 25/04/16	09:00	12	13.6	19.6	19.3	38.2	10.3	61.0
	11:00	10	13.6	19.7	19.5	37.8	11.7	70.0
	13:00	11	14.4	20.4	20.2	36.1	12.2	65.6
	15:00	8	14.3	20.9	20.3	37.3	12.6	58.4
	17:00	8	14.8	21.1	20.9	38.4	11.8	61.7
	Average Value	**10**	**14.1**	**20.3**	**20.0**	**37.6**	**11.7**	**63.3**
Tues 26/04/16	09:00	10	14.1	20.5	20.3	30.7	8.9	56.0
	11:00	10	14.3	21.1	21.2	32.7	9.5	57.3
	13:00	12	14.9	21.3	21.2	33.1	10.6	49.8
	15:00	12	15.7	22.8	22.8	29.7	11.4	48.8
	17:00	12	15.5	22.4	22.3	30.1	10.1	45.7
	Average Value	**11**	**14.9**	**21.6**	**21.6**	**31.3**	**10.1**	**51.5**
Wed 27/04/16	09:00	9	14.9	21.0	21.2	33.7	7.8	43.5
	11:00	9	15.6	21.6	21.9	37.1	8.3	44.8
	13:00	6	16.4	21.9	22.2	37.6	9.2	49.2
	15:00	10	16.9	22.4	22.7	38.1	10.8	48.7
	17:00	9	17.1	23.1	23.3	39.3	11.5	46.8
	Average Value	**9**	**16.2**	**22.0**	**22.3**	**37.2**	**9.5**	**46.6**
Thurs 28/04/16	09:00	5	14.5	19.6	19.8	39.4	7.8	61.2
	11:00	6	15.9	21.9	21.8	41.5	9.9	54.6
	13:00	8	16.1	22.4	22.2	35.3	11.7	44.7
	15:00	9	16.9	22.8	23.1	36.6	10.8	54.7
	17:00	6	16.9	23.1	22.8	36.2	10.1	62.1
	Average Value	**7**	**16.1**	**22.0**	**21.9**	**37.8**	**10.1**	**55.5**
Fri 29/04/16	09:00	7	15.9	21.3	21.5	36.7	7.1	54.8
	11:00	6	15.9	21.8	21.6	35.2	8.6	57.9
	13:00	2	16.3	22.4	22.3	36.3	9.2	60.4
	15:00	7	16.1	22.2	22.3	35.8	10.7	56.8
	17:00	N/A	N/A	N/A	N/A	N/A	11.1	45.9
	Average Value	**6**	**16.1**	**21.9**	**21.9**	**36.0**	**9.3**	**55.2**
Seasonal Average Value		**9**	**15.4**	**21.6**	**21.5**	**36.0**	**10.1**	**54.4**

Table 61 - BSRIA Environmental Ambient Data Overview (Handheld Measurements (Summer & Spring)

6.3 Workplace Temperatures, Humidity and CO2 Review

Seasonal data is represented within Fig's. 179-182 & 187-190 for both 5Plus and BSRIA supported by significant background daily (day/Night) data. Both spaces were seen to be obviously different and this was determined around number of daily occupants, modern N.V design at 5Plus, the workplace layouts in terms of how the space was arranged and the lack of any ventilation control at BSRIA.

Neither site has previously received any POE assessment or empirical measurement and therefore there was no previous performance data to assess. The data provided is therefore how the spaces were performing as actual free running spaces without any recent adjustments or system re-commissioning.

6.4 BSRIA Seasonal Site Review

Upon review of the survey feedback from BSRIA staff and general discussions during the week long site attendance, it was understood that during seasonal periods (winter & spring) there was a feeling of lethargy and tiredness assumed to be linked to lack of ventilation. A number of portable fans were also noted around the workplace related to summer and warmer seasonal days were the windows were unable to be opened for various reasons either noise or breeze etc.

Fig. 179 ***spring,*** indicates higher levels of CO_2 due to the cold days and nights requiring the windows to be closed for most of the time. Limits are only just exceeded, but do have periods of higher levels. Temperature and humidity are within expected limits. Interestingly the night time decay readings take all night to return to normal background levels, this will obviously exacerbate the daily readings if the night time purge was restricted.

Fig. 180 ***summer***, indicates a much-improved and reduced level of CO_2 primarily due to more windows being open longer into the night. The environment is much more as expected within acceptable limits of CO_2 however, the night purge appears to take a similar time as in spring to reduce levels to background values. Temperature has increased slightly as to be expected, and could be said to be outside normal limits for temperature. Humidity values were acceptable.

Fig. 181 ***autumn***, we see higher than expected levels of CO_2 suggesting natural ventilation has been restricted. The external air temperature had reduced which is why the windows were not open and hence higher levels experienced.

Fig. 182 indicates the winter (5-day) period displaying the day & night values as discussed previously. As anticipated the high values of CO_2 would suggest an impact would be experienced by the occupants of either lethargy or tiredness. Values are considerably higher than acceptable limits <1000ppm, caused by the windows being closed and no means of mechanical ventilation. The air exchange within the space is via doors opening to the staircase, however this is not vented to atmosphere and therefore the space is enclosed. Interestingly the night time period does not allow any evacuation of the space, as again the windows are closed. This therefore sets a normal level of background CO_2 within the space ahead of occupants arriving compounding the day time issue. The average night time mean is recorded at 1051 ppm confirming the only option for CO_2 levels is to increase further during the day. This affect would realistically continue for sometime subject to external temperatures and the windows being closed therefore an area of real concern. Temperature and humidity values would appear satisfactory with good control of the heating system. Humidity is free running relative to occupants and air leakage through the façade.

With respect to noise (Fig's183-186) we see similar seasonal changes in performance, but this time as a result of the windows being open in summer and external noise entering the space. The internal noise levels generally seem to be high and during most times outside considered designed best practice. Various survey responses have stated occupants tune out noise, however, it consistently features within POE responses as a concern and nuisance. A RAG status table is provided within each Figure to provide an appreciation of the noise issues.

Seasonally we can therefore observe some discrete changes in workplace performance particularly CO_2 driven primarily from an un-ventilated space. Temperature and humidity are within expected norms for the various periods measured. Noise similarly provides seasonal differences that may need to be addressed.

Day Time (%rh) Readings	
49	%rh Average (Mean)
54	%rh max
46	%rh min
47	%rh Mode
4	%rh Variance
2	%rh Standard Deviation

Night Time (%rh) Readings	
52	%rh Average (Mean)
54	%rh max
47	%rh min
53	%rh Mode
2	%rh Variance
2	%rh Standard Deviation

Day Time v Night Time (%rh) Readings		
-3	%rh Average (Mean)	increase
-1	%rh max	increase
-1	%rh min	increase
-6	%rh Mode	increase
N/A	%rh Variance	
0	%rh Standard Deviatior	increase

Day Time (Temp) Readings	
23	deg.C Temp Average (Mean)
24	deg.C Temp max
19	deg.C Temp min
22	deg.C Temp Mode
1	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Night Time (Temp) Readings	
19	deg.C Temp Average (Mean)
23	deg.C Temp max
17	deg.C Temp min
20	deg.C Temp Mode
2	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Day Time v Night Time (Temp) Readings		
3	deg.C Temp Average (I	increase
2	deg.C Temp max	increase
2	deg.C Temp min	increase
2	deg.C Temp Mode	increase
N/A	deg.C Temp Variance	
0	deg.C Temp StdDev	increase

Day Time (CO2) Readings	
1495	CO2 Average (Mean)
2632	CO2 max
618	CO2 min
1054	CO2 Mode
148889	CO2 Variance
386	CO2 Standard Deviation

Night Time (CO2) Readings	
1051	CO2 Average (Mean)
1830	CO2 max
626	CO2 min
665	CO2 Mode
82657	CO2 Variance
288	CO2 Standard Deviation

Day Time v Night Time (CO2) Readings		
443	CO2 Average (Mean)	increase
802	CO2 max	increase
-8	CO2 min	increase
389	CO2 Mode	increase
N/A	CO2 Variance	
98	CO2 Standard Deviatior	increase

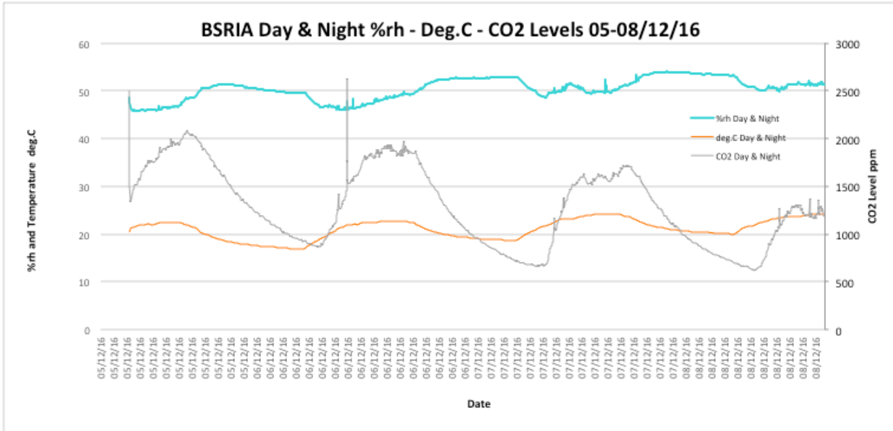


Fig. 179 - BSRIA Environmental Tabular and Graphical Seasonal Data (Winter)

Day Time (%rh) Readings	
56	%rh Average (Mean)
59	%rh max
48	%rh min
56	%rh Mode
2	%rh Variance
2	%rh Standard Deviation

Night Time (%rh) Readings	
57	%rh Average (Mean)
59	%rh max
54	%rh min
56	%rh Mode
2	%rh Variance
1	%rh Standard Deviation

Day Time (Temp) Readings	
22	deg. C Temp Average (Mean)
23	deg. C Temp max
20	deg. C Temp min
23	deg. C Temp Mode
0	deg. C Temp Variance
1	deg. C Temp Standard Deviation

Night Time (Temp) Readings	
21	deg. C Temp Average (Mean)
22	deg. C Temp max
20	deg. C Temp min
21	deg. C Temp Mode
0	deg. C Temp Variance
0	deg. C Temp Standard Deviation

Day Time V Night Time (%rh) Readings		
-1	%rh Average (Mean)	increase
0	%rh max	increase
-5	%rh min	increase
0	%rh Mode	increase
N/A	%rh Variance	
0	%rh Standard Deviatior	increase

Day Time V Night Time (Temp) Readings		
1	deg. C Temp Average (I	increase
1	deg. C Temp max	increase
0	deg. C Temp min	increase
2	deg. C Temp Mode	increase
N/A	deg. C Temp Variance	
0	deg. C Temp StdDev	increase

Day Time (CO2) Readings	
951	CO2 Average (Mean)
1503	CO2 max
434	CO2 min
814	CO2 Mode
67991	CO2 Variance
261	CO2 Standard Deviation

Night Time (CO2) Readings	
715	CO2 Average (Mean)
1105	CO2 max
505	CO2 min
539	CO2 Mode
21519	CO2 Variance
147	CO2 Standard Deviation

Day Time V Night Time (CO2) Readings		
236	CO2 Average (Mean)	increase
398	CO2 max	increase
-71	CO2 min	increase
275	CO2 Mode	increase
N/A	CO2 Variance	
114	CO2 Standard Deviatioı	increase

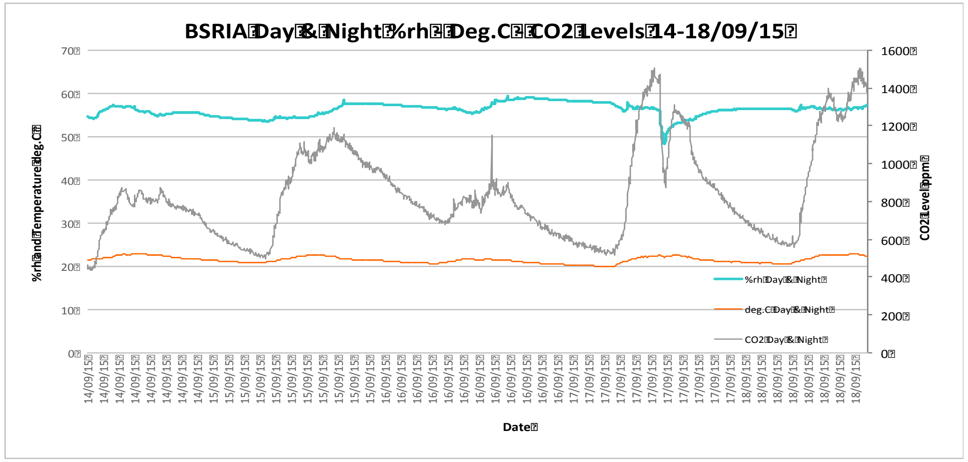


Fig.180 - BSRIA Environmental Tabular and Graphical Seasonal Data (Autumn)

Day Time (%rh) Readings	
45	%rh Average (Mean)
57	%rh max
39	%rh min
40	%rh Mode
22	%rh Variance
5	%rh Standard Deviation

Night Time (%rh) Readings	
49	%rh Average (Mean)
56	%rh max
42	%rh min
49	%rh Mode
7	%rh Variance
3	%rh Standard Deviation

Day Time v Night Time (%rh) Readings		
-4	%rh Average (Mean)	increase
1	%rh max	increase
-3	%rh min	increase
-9	%rh Mode	increase
N/A	%rh Variance	
2	%rh Standard Deviatior	increase

Day Time (Temp) Readings	
26	deg.C Temp Average (Mean)
28	deg.C Temp max
21	deg.C Temp min
27	deg.C Temp Mode
1	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Night Time (Temp) Readings	
25	deg.C Temp Average (Mean)
23	deg.C Temp max
24	deg.C Temp min
26	deg.C Temp Mode
1	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Day Time v Night Time (Temp) Readings		
1	deg.C Temp Average (M	increase
5	deg.C Temp max	increase
-3	Temp min	increase
2	deg.C Temp Mode	increase
N/A	deg.C Temp Variance	
0	deg.C Temp StdDev	increase

Day Time (CO2) Readings	
549	CO2 Average (Mean)
669	CO2 max
469	CO2 min
1054	CO2 Mode
1656	CO2 Variance
41	CO2 Standard Deviation

Night Time (CO2) Readings	
550	CO2 Average (Mean)
620	CO2 max
500	CO2 min
550	CO2 Mode
498	CO2 Variance
22	CO2 Standard Deviation

Day Time v Night Time (CO2) Readings		
-1	CO2 Average (Mean)	increase
49	CO2 max	increase
-31	CO2 min	increase
504	CO2 Mode	increase
N/A	CO2 Variance	
18	CO2 Standard Deviatior	increase

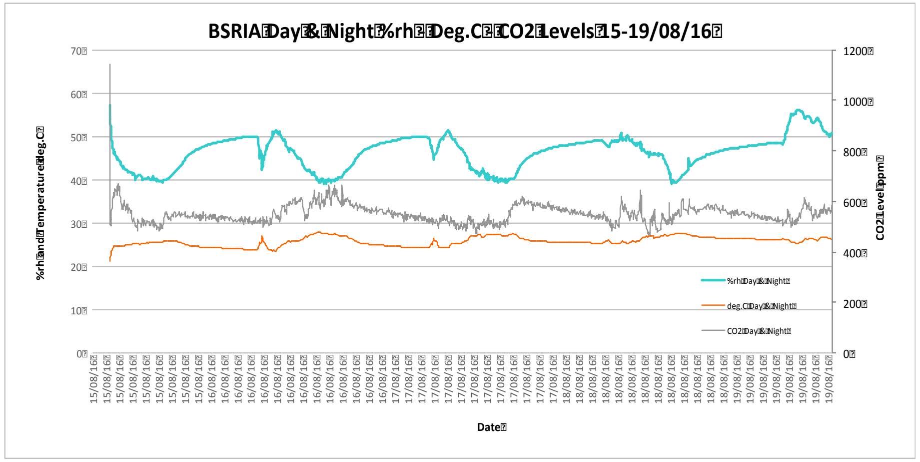


Fig. 181 - BSRIA Environmental Tabular and Graphical Seasonal Data (Summer)

Day Time (%rh) Readings	
36	%rh Average (Mean)
42	%rh max
30	%rh min
36	%rh Mode
6	%rh Variance
3	%rh Standard Deviation

Night Time (%rh) Readings	
39	%rh Average (Mean)
43	%rh max
36	%rh min
40	%rh Mode
4	%rh Variance
2	%rh Standard Deviation

Day Time (Temp) Readings	
22	deg. C Temp Average (Mean)
24	deg. C Temp max
21	deg. C Temp min
23	deg. C Temp Mode
0	deg. C Temp Variance
1	deg. C Temp Standard Deviation

Night Time (Temp) Readings	
20	deg. C Temp Average (Mean)
23	deg. C Temp max
19	deg. C Temp min
20	deg. C Temp Mode
1	deg. C Temp Variance
1	deg. C Temp Standard Deviation

Day Time v Night Time (%rh) Readings			
	-3	%rh Average (Mean)	increase
	-1	%rh max	increase
	-6	%rh min	increase
	-4	%rh Mode	increase
N/A		%rh Variance	
	1	%rh Standard Deviatior	increase

Day Time v Night Time (Temp) Readings			
	2	deg. C Temp Average (I	increase
	1	deg. C Temp max	increase
	2	deg. C Temp min	increase
	2	deg. C Temp Mode	increase
N/A		deg. C Temp Variance	
	0	deg. C Temp StdDev	increase

Day Time (CO2) Readings	
1103	CO2 Average (Mean)
1942	CO2 max
544	CO2 min
1054	CO2 Mode
32247	CO2 Variance
180	CO2 Standard Deviation

Night Time (CO2) Readings	
691	CO2 Average (Mean)
1157	CO2 max
486	CO2 min
505	CO2 Mode
13750	CO2 Variance
117	CO2 Standard Deviation

Day Time v Night Time (CO2) Readings			
	412	CO2 Average (Mean)	increase
	785	CO2 max	increase
	58	CO2 min	increase
	549	CO2 Mode	increase
N/A		CO2 Variance	
	62	CO2 Standard Deviatior	increase

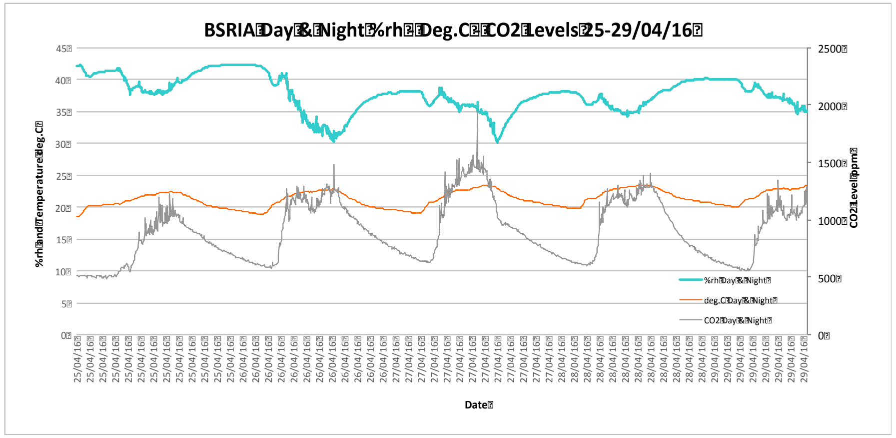


Fig. 182 - BSRIA Environmental Tabular and Graphical Seasonal Data (Spring)

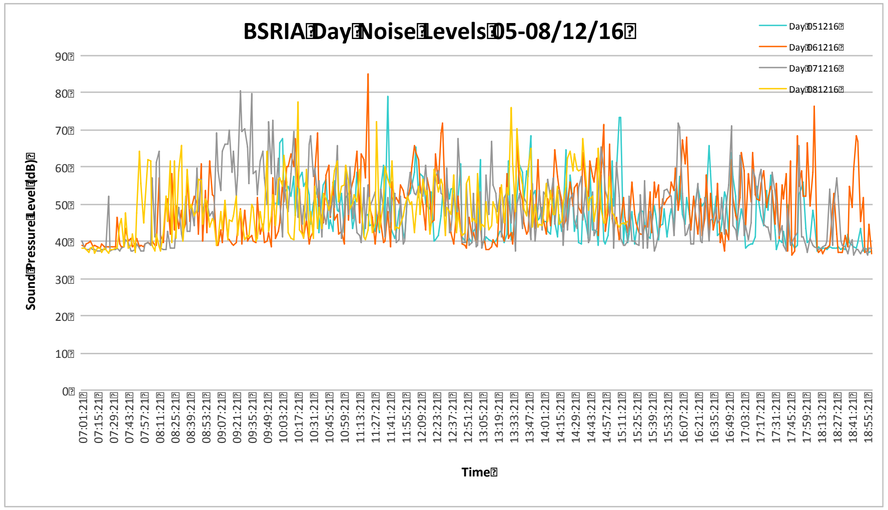
BSRIA 05-081216

Day Time (db) Readings	
48	dB Average (Mean)
85	dB max
36	dB min
38	dB Mode
72	dB Variance
2	dB Standard Deviation

Night Time (db) Readings	
38	dB Average (Mean)
62	dB max
35	dB min
37	dB Mode
3	dB Variance
2	dB Standard Deviation

Day Time v Night Time (db) Readings		
10	dB Average (Mean)	increase
23	dB max	increase
1	dB min	increase
1	dB Mode	increase
N/A	dB Variance	
0	dB Standard Deviation	increase

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
05/12/16	06/12/16	07/12/16	08/12/16	09/12/16
47	48	48	49	N/A Transfer to 5+
79	85	81	78	
37	36	36	37	
38	39	38	45	
58	76	82	63	
8	9	9	8	



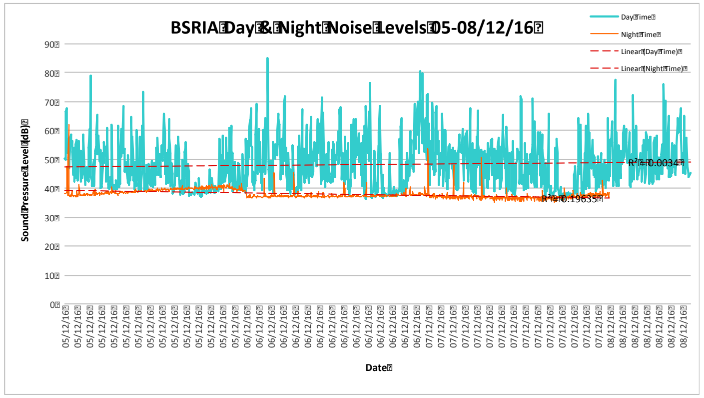


Fig. 183 - BSRIA Environmental (Noise) Tabular and Graphical Seasonal Data (Winter)

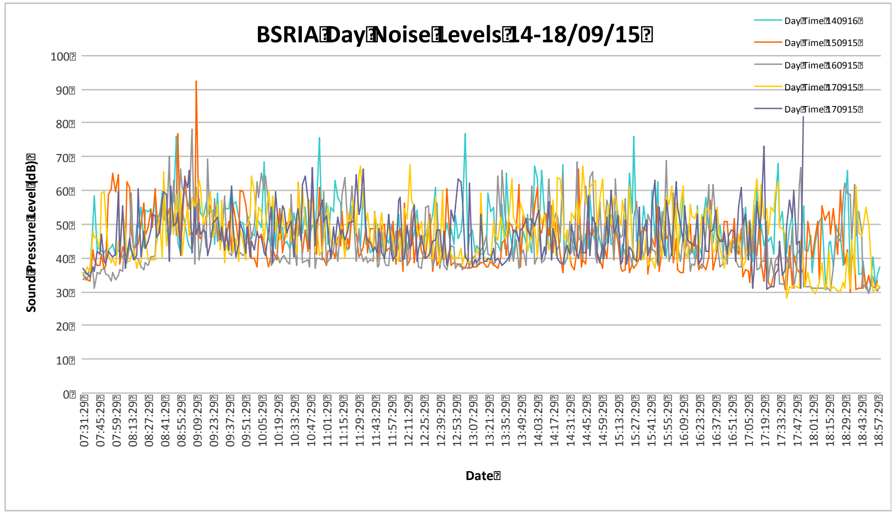
BSRIA 14-180915

Day Time (db) Readings	
46	dB Average (Mean)
92	dB max
28	dB min
41	dB Mode
70	dB Variance
3	dB Standard Deviation

Night Time (db) Readings	
31	dB Average (Mean)
64	dB max
26	dB min
30	dB Mode
8	dB Variance
3	dB Standard Deviation

Day Time				
Mon	Tues	Wed	Thurs	Fri
14/09/15	15/09/15	16/09/15	17/09/15	18/09/15
48	45	45	47	47
77	92	78	68	82
30	30	30	28	31
44	51	38	31	45
56	65	88	74	60
8	8	9	9	8

Day Time v Night Time (db) Readings		
15	dB Average (Mean)	increase
29	dB max	increase
2	dB min	increase
11	dB Mode	increase
N/A	dB Variance	
0	dB Standard Deviation	increase



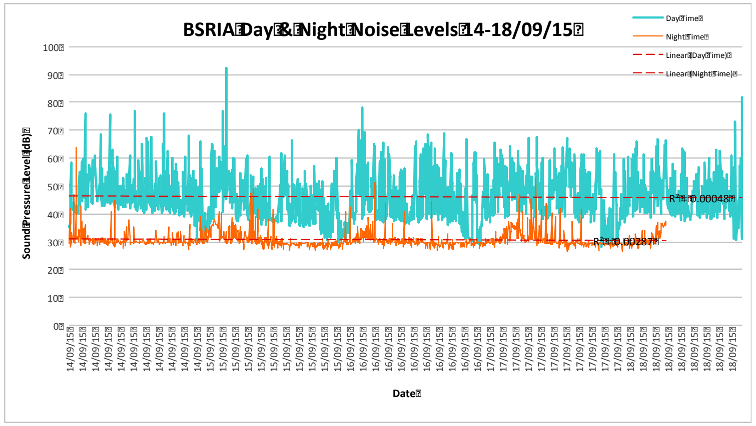


Fig. 184 - BSRIA Environmental (Noise) Tabular and Graphical Seasonal Data (Autumn)

BSRIA 15-190816

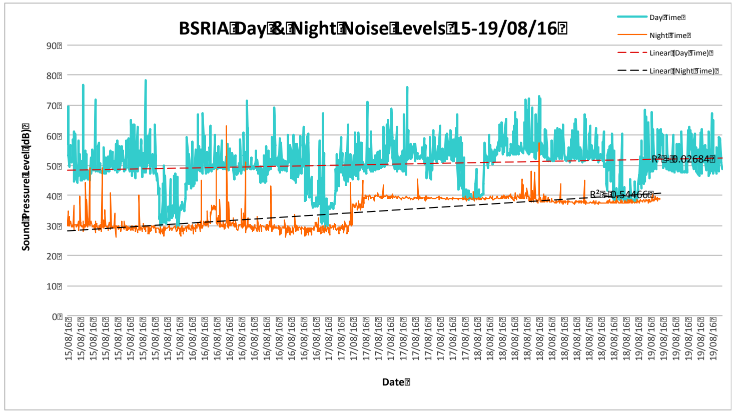
Day Time (db) Readings	
50	dB Average (Mean)
78	dB max
29	dB min
49	dB Mode
51	dB Variance
7	dB Standard Deviation

V

Night Time (db) Readings	
34	dB Average (Mean)
63	dB max
26	dB min
39	dB Mode
24	dB Variance
5	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
15/08/16	16/08/16	17/08/16	18/08/16	19/08/16
48	49	50	53	50
78	71	76	73	68
29	29	36	38	38
48	49	49	52	49
66	43	45	43	42
8	7	7	7	7

Day Time V Night Time (db) Readings			
	16	dB Average (Mean)	increase
	15	dB max	increase
	3	dB min	increase
	10	dB Mode	increase
N/A		dB Variance	
	2	dB Standard Deviation	increase



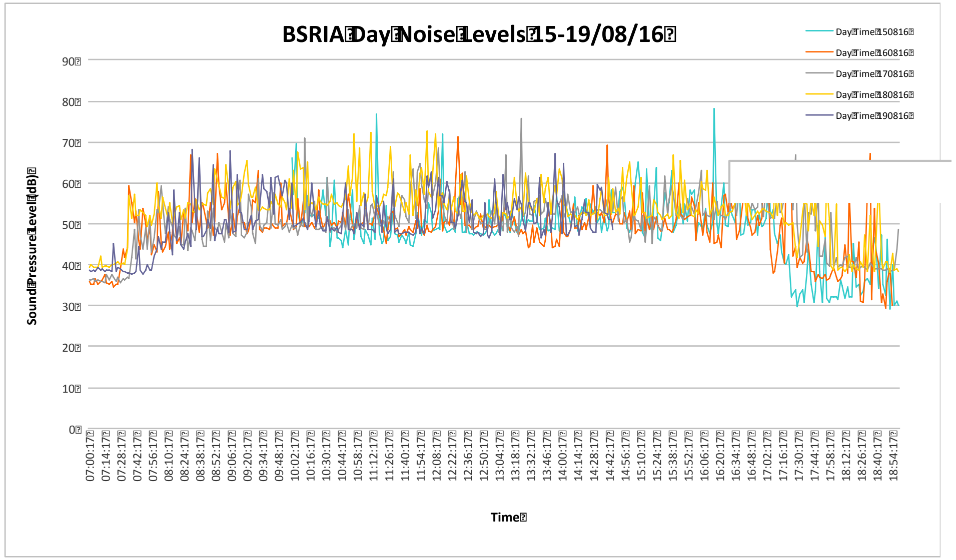


Fig. 185 - BSRIA Environmental (Noise) Tabular and Graphical Seasonal Data (Autumn)

BSRIA 15-190816

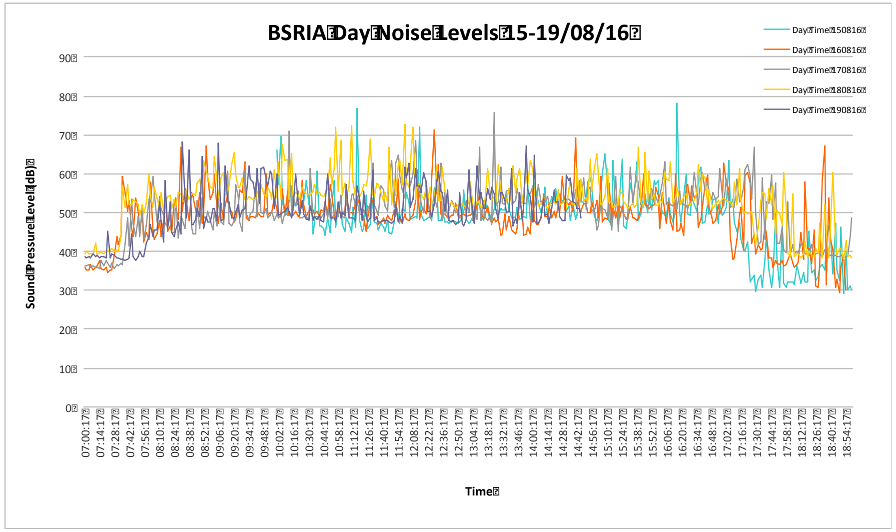
Day Time (db) Readings	
50	dB Average (Mean)
78	dB max
29	dB min
49	dB Mode
51	dB Variance
7	dB Standard Deviation

V

Night Time (db) Readings	
34	dB Average (Mean)
63	dB max
26	dB min
39	dB Mode
24	dB Variance
5	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
15/08/16	16/08/16	17/08/16	18/08/16	19/08/16
48	49	50	53	50
78	71	76	73	68
29	29	36	38	38
48	49	49	52	49
66	43	45	43	42
8	7	7	7	7

Day Time v Night Time (db) Readings		
16	dB Average (Mean)	increase
15	dB max	increase
3	dB min	increase
10	dB Mode	increase
N/A	dB Variance	
2	dB Standard Deviation	increase



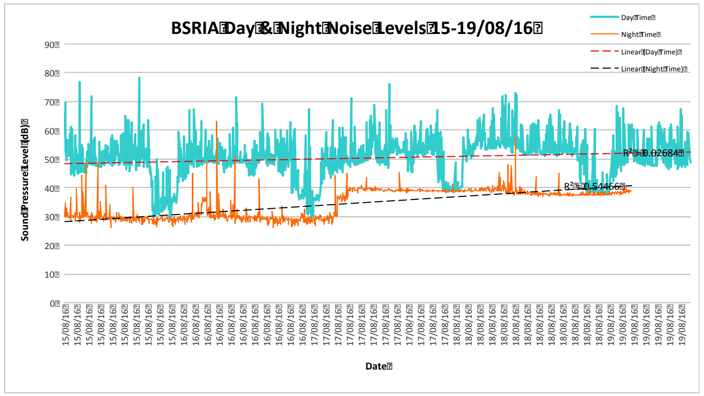


Fig. 186 - BSRIA Environmental (Noise) Tabular and Graphical Seasonal Data (Summer)

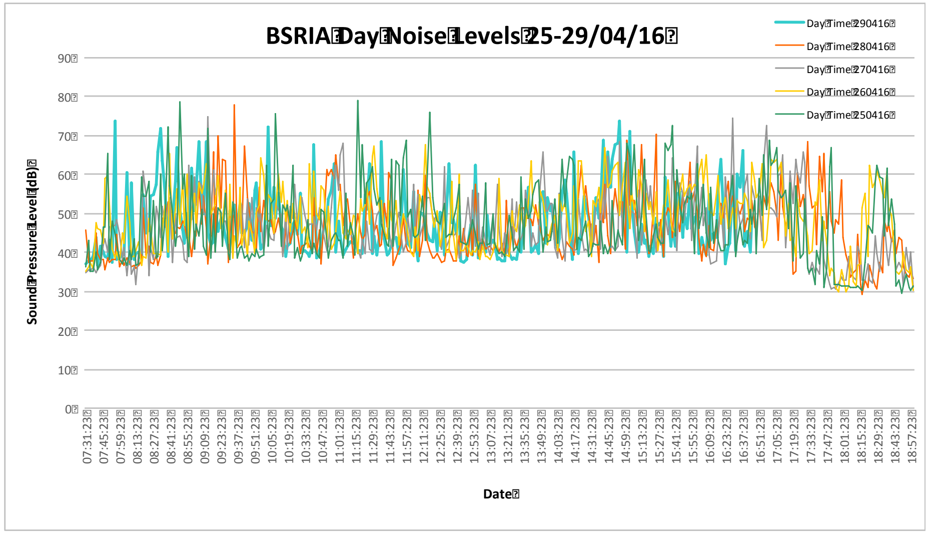
BSRIA 25-290416

Day Time (db) Readings	
47	dB Average (Mean)
79	dB max
29	dB min
79	dB Mode
29	dB Variance
39	dB Standard Deviation

Night Time (db) Readings	
31	dB Average (Mean)
66	dB max
27	dB min
66	dB Mode
27	dB Variance
30	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
25/04/16	26/04/16	27/04/16	28/04/16	29/04/16
47	49	47	46	47
79	68	75	78	74
30	30	31	29	37
39	46	47	45	40
98	68	72	64	72
10	8	8	8	9

Day Time V Night Time (db) Readings		
16	dB Average (Mean)	increase
13	dB max	increase
2	dB min	increase
13	dB Mode	increase
N/A	dB Variance	
9	dB Standard Deviation	increase



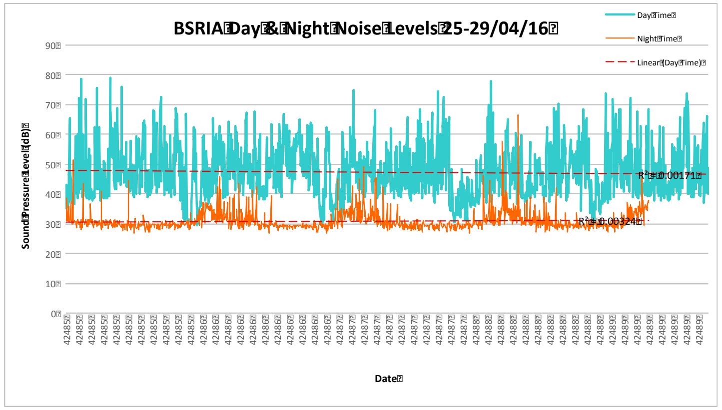


Fig. 187 - BSRIA Environmental (Noise) Tabular and Graphical Seasonal Data (Spring

6.5 5Plus Architects Seasonal Site Review

Upon review of the survey feedback from 5Plus staff and general discussions during the week-long site attendance, internal & external noise nuisance, smells & odours appeared to be the prominent issues facing staff. The design of the Hive is of modern minimalist design with hard surfaces and no plants, but incorporates an intelligent naturally ventilated space using semi-automatic vents and operable windows to create a cross flow of air.

Fig. 187 indicates the ***winter,*** (5-day) period displaying the day & night values as discussed previously. Values were higher than acceptable limits <1000ppm, caused by the windows being closed, vents being fully closed unnecessarily and no means of mechanical ventilation. Due to the design of the N.V semi-automated vents being forced open during the night, the space is purged with fresh air as indicated in the background CO2 level achieved. Temperature and humidity values would appear satisfactory with good control of the heating system. Humidity is free running relative to occupants and air leakage through the façade and semi automated vents.

Fig. 188 ***autumn,*** unexpectedly indicated a much higher CO_2 value than expected as discussed above, this was also traced to a faulty vent controller. Temperature and humidity values were within expected design norms. The average night-time mean (autumn) is recorded at 625 ppm slightly higher than external however acceptable.

Fig. 189 ***summer,*** indicates a much-improved and reduced level of CO_2 primarily due to more windows being open longer into the night and full vent control operating. The environment is much more as expected within acceptable limits of CO_2 with a night purge of the space again assisting. Temperature and humidity has increased slightly as to be expected, but could be said to be outside normal limits for temperature.

Fig. 190 ***spring***, takes us back to higher levels of CO_2 due again to the cold days and nights requiring the windows and vent again to be closed for most of the time. Limits are only just exceeded but do have periods of higher levels. Temperature and humidity are within expected limits.

With respect to noise (Fig's. 191-194) we see similar seasonal changes in performance as noted at BSRIA, and as a result of the windows being open in summer and external noise entering the space. The internal noise levels generally seem to be high and during most times significantly outside considered designed best practice. Various survey responses have stated they tune out noise, however, it consistently features within POE responses as a concern and nuisance. The noise issue at 5Plus reflects POE feedback and should be addressed.

Seasonally we can therefore notice some discrete changes in workplace performance particularly CO_2 driven as the space is not mechanically ventilated and due to system faults. Temperature and humidity are within expected norms. Noise remains consistent throughout the seasons, but has specific daily signatures and values.

5Plus 12-161216

Day Time (%rh) Readings		
40	%rh Average (Mean)	
45	%rh max	
35	%rh min	
42	%rh Mode	
4	%rh Variance	
2	%rh Standard Deviation	

Night Time (%rh) Readings	
40	%rh Average (Mean)
44	%rh max
37	%rh min
40	%rh Mode
6	%rh Variance
2	%rh Standard Deviation

Day Time (Temp) Readings	
24	deg.C Temp Average (Mean)
25	deg.C Temp max
23	deg.C Temp min
24	deg.C Temp Mode
0	deg.C Temp Variance
0	deg.C Temp Standard Deviation

Night Time (Temp) Readings	
24	deg.C Temp Average (Mean)
24	deg.C Temp max
23	deg.C Temp min
24	deg.C Temp Mode
0	deg.C Temp Variance
0	deg.C Temp Standard Deviation

Day Time V Night Time (%rh) Readings		
0	%rh Average (Mean)	increase
0	%rh max	increase
-1	%rh min	decrease
2	%rh Mode	increase
N/A	%rh Variance	
0	%rh StdDev	increase

Day Time V Night Time (Temp) Readings		
0	deg.C Temp Average (M	increase
1	deg.C Temp max	
0	deg.C Temp min	
0	deg.C Temp Mode	increase
N/A	deg.C Temp Variance	
0	deg.C Temp StdDev	

Day Time (CO2) Readings	
791	CO2 Average (Mean)
1328	CO2 max
506	CO2 min
755	CO2 Mode
34210	CO2 Variance
185	CO2 Standard Deviation

Night Time (CO2) Readings	
582	CO2 Average (Mean)
779	CO2 max
505	CO2 min
538	CO2 Mode
3935	CO2 Variance
63	CO2 Standard Deviation

Day Time V Night Time (CO2) Readings		
208	CO2 Average (Mean)	increase
549	CO2 max	increase
1	CO2 min	increase
217	CO2 Mode	increase
N/A	CO2 Variance	
122	CO2 StdDev	increase

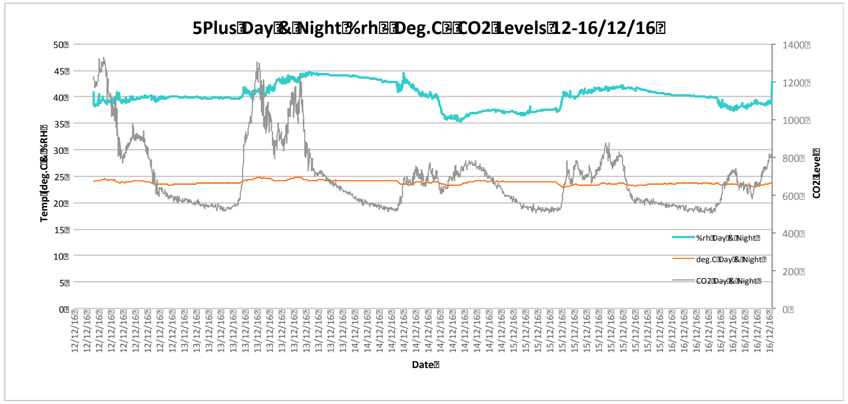


Fig. 188 - 5Plus Environmental Tabular and Graphical Seasonal Data (Winter)

5Plus 16-201115

Day Time (%rh) Readings

46	%rh Average (Mean)
52	%rh max
36	%rh min
47	%rh Mode
13	%rh Variance
4	%rh Standard Deviation

Night Time (%rh) Readings

43	%rh Average (Mean)
50	%rh max
39	%rh min
43	%rh Mode
5	%rh Variance
2	%rh Standard Deviation

Day Time V Night Time (%rh) Readings

2	%rh Average (Mean)	increase
1	%rh max	increase
-3	%rh min	decrease
4	%rh Mode	increase
N/A	%rh Variance	
1	%rh StdDev	increase

Day Time (Temp) Readings

23	deg.C Temp Average (Mean)
24	deg.C Temp max
21	deg.C Temp min
23	deg.C Temp Mode
0	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Night Time (Temp) Readings

22	deg.C Temp Average (Mean)
24	deg.C Temp max
21	deg.C Temp min
22	deg.C Temp Mode
0	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Day Time V Night Time (Temp) Readings

1	deg.C Temp Average (M	increase
0	deg.C Temp max	
0	deg.C Temp min	
1	deg.C Temp Mode	increase
N/A	deg.C Temp Variance	
0	deg.C Temp StdDev	

Day Time (CO2) Readings

1266	CO2 Average (Mean)
2067	CO2 max
457	CO2 min
1043	CO2 Mode
185710	CO2 Variance
431	CO2 Standard Deviation

Night Time (CO2) Readings

625	CO2 Average (Mean)
1660	CO2 max
447	CO2 min
480	CO2 Mode
47522	CO2 Variance
218	CO2 Standard Deviation

Day Time V Night Time (CO2) Readings

641	CO2 Average (Mean)	increase
407	CO2 max	increase
10	CO2 min	increase
563	CO2 Mode	increase
N/A	CO2 Variance	
213	CO2 StdDev	increase

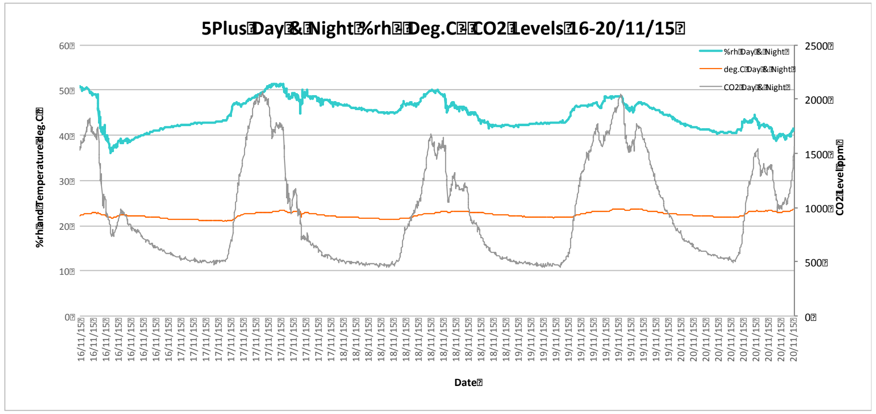


Fig. 189 - 5Plus Environmental Tabular and Graphical Seasonal Data (Autumn)

5Plus 13-170715

Day Time (%rh) Readings	
44	%rh Average (Mean)
60	%rh max
32	%rh min
43	%rh Mode
60	%rh Variance
8	%rh Standard Deviation

Night Time (%rh) Readings	
43	%rh Average (Mean)
55	%rh max
33	%rh min
43	%rh Mode
31	%rh Variance
6	%rh Standard Deviation

Day Time V Night Time (%rh) Readings		
1	%rh Average (Mean)	increase
5	%rh max	increase
-2	%rh min	decrease
0	%rh Mode	increase
N/A	%rh Variance	
2	%rh StdDev	increase

Day Time (Temp) Readings	
24	deg.C Temp Average (Mean)
26	deg.C Temp max
20	deg.C Temp min
25	deg.C Temp Mode
1	deg.C Temp Variance
1	deg.C Temp Standard Deviation

Night Time (Temp) Readings	
25	deg.C Temp Average (Mean)
27	deg.C Temp max
25	deg.C Temp min
25	deg.C Temp Mode
0	deg.C Temp Variance
0	deg.C Temp Standard Deviation

Day Time V Night Time (Temp) Readings		
-1	deg.C Temp Average (M	decrease
-1	deg.C Temp max	decrease
-5	deg.C Temp min	decrease
0	deg.C Temp Mode	
N/A	deg.C Temp Variance	
1	deg.C Temp StdDev	increase

Day Time (CO2) Readings	
532	CO2 Average (Mean)
722	CO2 max
445	CO2 min
500	CO2 Mode
2317	CO2 Variance
48	CO2 Standard Deviation

Night Time (CO2) Readings	
497	CO2 Average (Mean)
592	CO2 max
430	CO2 min
472	CO2 Mode
966	CO2 Variance
31	CO2 Standard Deviation

Day Time V Night Time (CO2) Readings		
35	CO2 Average (Mean)	increase
130	CO2 max	increase
15	CO2 min	increase
28	CO2 Mode	increase
N/A	CO2 Variance	
17	CO2 StdDev	increase

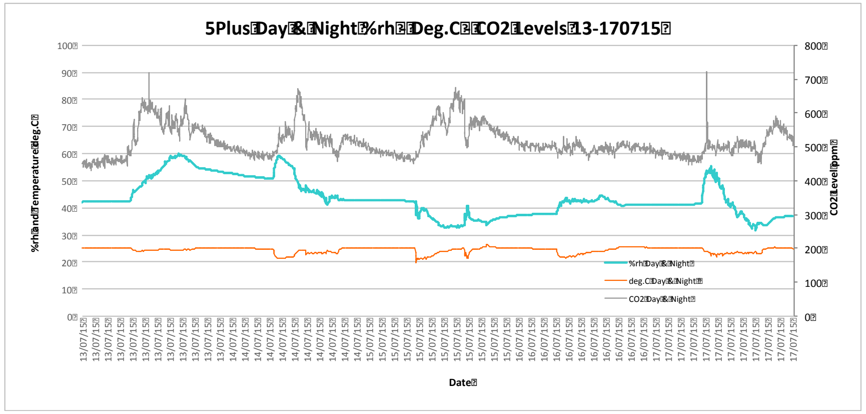


Fig. 190 - 5Plus Environmental Tabular and Graphical Seasonal Data (Summer)

5Plus 14-180316

Day Time (%rh) Readings

30	%rh Average (Mean)
37	%rh max
23	%rh min
31	%rh Mode
9	%rh Variance
3	%rh Standard Deviation

Night Time (%rh) Readings

30	%rh Average (Mean)
37	%rh max
25	%rh min
30	%rh Mode
7	%rh Variance
3	%rh Standard Deviation

Day Time v Night Time (%rh) Readings

0	%rh Average (Mean)	
0	%rh max	
-3	%rh min	decrease
0	%rh Mode	
N/A	%rh Variance	
0	%rh Standard Deviation	

Day Time (Temp) Readings

24	deg.C Temp Average (Mean)
25	deg.C Temp max
23	deg.C Temp min
25	deg.C Temp Mode
0	deg.C Temp Variance
0	deg.C Temp Standard Deviation

Night Time (Temp) Readings

24	deg.C Temp Average (Mean)
25	deg.C Temp max
24	deg.C Temp min
24	deg.C Temp Mode
0	deg.C Temp Variance
0	deg.C Temp Standard Deviation

Day Time v Night Time (Temp) Readings

0	deg.C Temp Average (Mean)	
0	deg.C Temp max	
-1	deg.C Temp min	decrease
1	deg.C Temp Mode	increase
N/A	deg.C Temp Variance	
0	deg.C Temp StdDev	

Day Time (CO2) Readings

882	CO2 Average (Mean)
1344	CO2 max
500	CO2 min
1006	CO2 Mode
39094	CO2 Variance
198	CO2 Standard Deviation

Night Time (CO2) Readings

649	CO2 Average (Mean)
928	CO2 max
518	CO2 min
552	CO2 Mode
7754	CO2 Variance
88	CO2 StdDev

Day Time v Night Time (CO2) Readings

233	CO2 Average (Mean)	increase
416	CO2 max	increase
-18	CO2 min	decrease
454	CO2 Mode	increase
N/A	CO2 Variance	
110	CO2 StdDev	increase

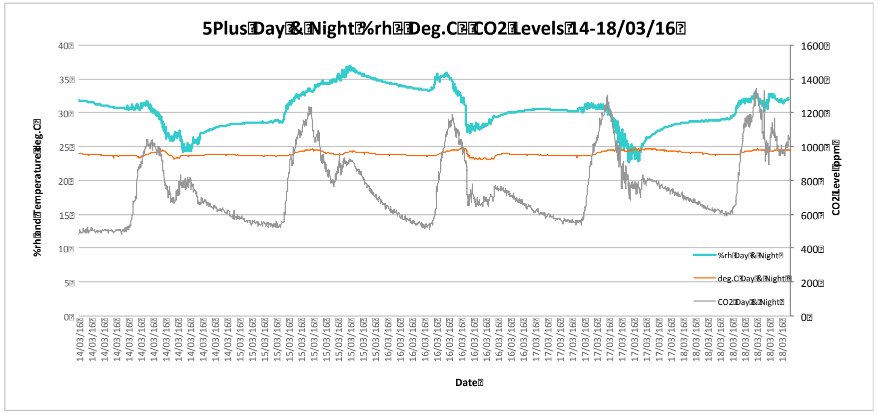


Fig. 191 - 5Plus Environmental Tabular and Graphical Seasonal Data (Spring)

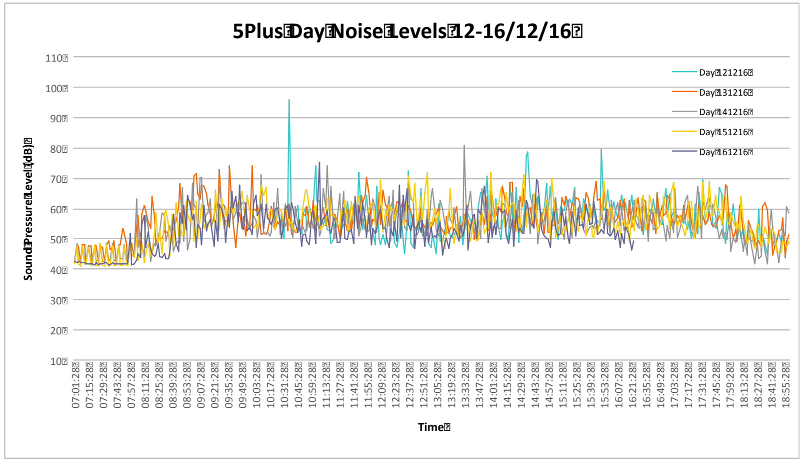
5Plus 12-161216

Day Time (db) Readings	
55	dB Average (Mean)
96	dB max
41	dB min
54	dB Mode
42	dB Variance
6	dB Standard Deviation

Night Time (db) Readings	
45	dB Average (Mean)
65	dB max
27	dB min
42	dB Mode
17	dB Variance
4	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
12/12/16	13/12/16	14/12/16	15/12/16	16/12/16
57	56	55	56	53
96	74	81	72	75
42	42	42	41	41
61	54	55	55	42
45	34	41	42	41
7	6	6	6	6

Day Time v Night Time (db) Readings			
	10	dB Average (Mean)	increase
	31	dB max	increase
	14	dB min	increase
	12	dB Mode	increase
N/A		dB Variance	
	2	dB Standard Deviation	increase



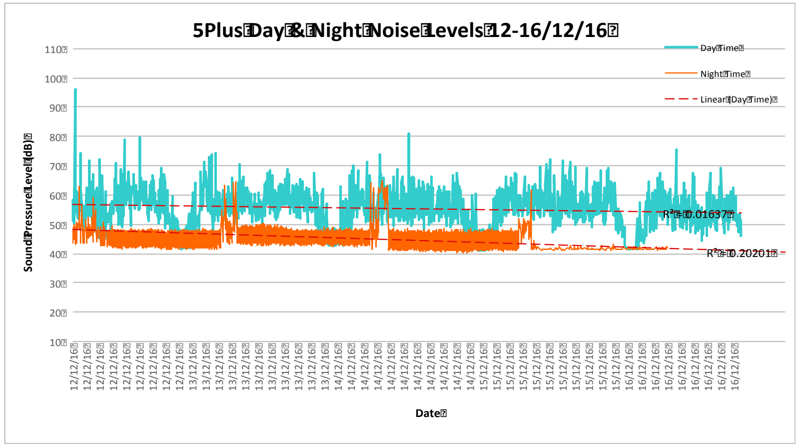


Fig. 192 - 5Plus Environmental (Noise) Tabular and Graphical Seasonal Data (Winter)

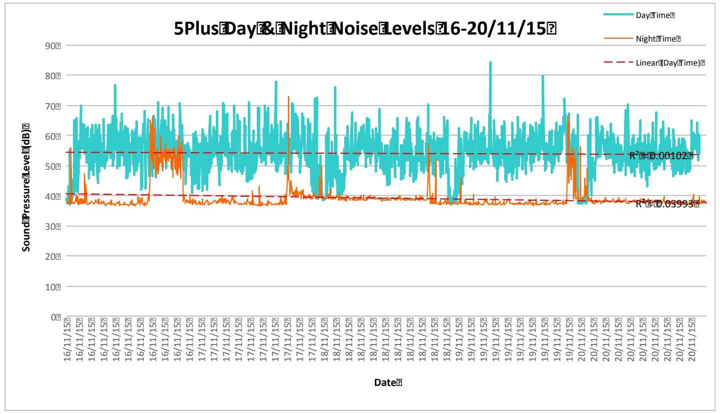
5Plus 16-201115

Day Time (db) Readings	
54	dB Average (Mean)
84	dB max
37	dB min
55	dB Mode
45	dB Variance
7	dB Standard Deviation

Night Time (db) Readings	
39	dB Average (Mean)
73	dB max
27	dB min
37	dB Mode
18	dB Variance
4	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
16/11/15	17/11/15	18/11/15	19/11/15	20/11/15
55	55	53	55	53
77	78	76	84	70
37	39	38	37	37
60	53	52	54	53
43	48	43	43	40
7	7	7	7	6

Day Time v Night Time (db) Readings			
	15	dB Average (Mean)	increase
	12	dB max	increase
	10	dB min	increase
	18	dB Mode	increase
N/A		dB Variance	
	2	dB Standard Deviation	increase



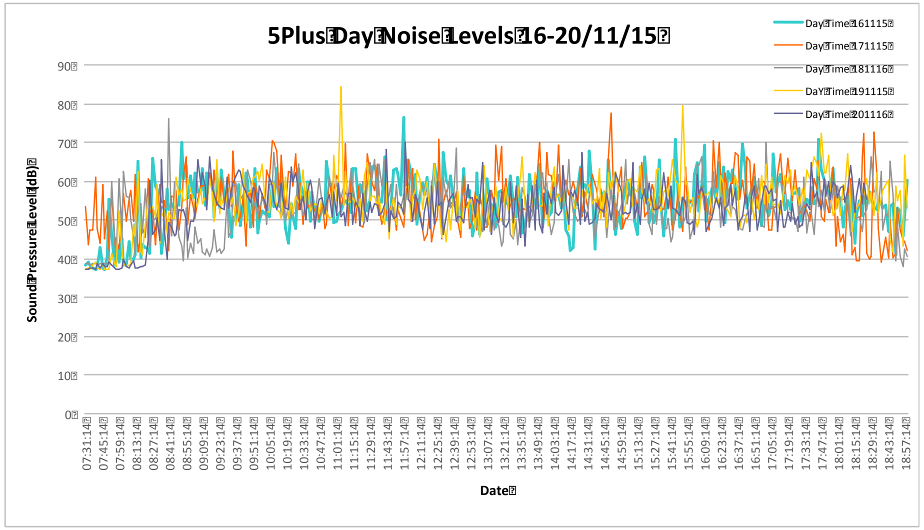


Fig. 193 - 5Plus Environmental (Noise) Tabular and Graphical Seasonal Data (Autumn)

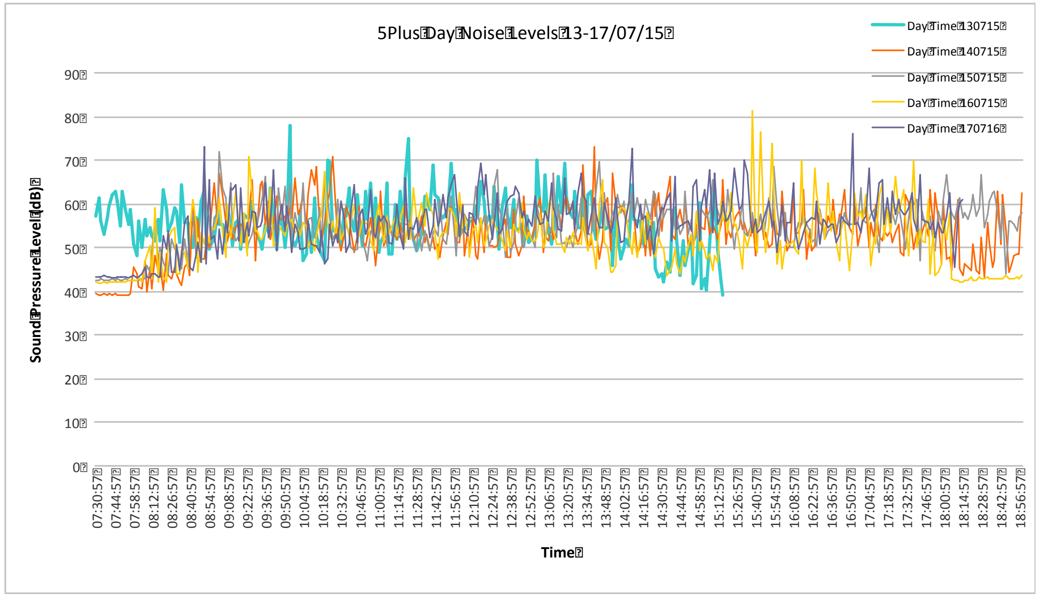
5Plus 13-170715

Day Time (db) Readings	
54	dB Average (Mean)
81	dB max
39	dB min
55	dB Mode
40	dB Variance
6	dB Standard Deviation

Night Time (db) Readings	
42	dB Average (Mean)
73	dB max
39	dB min
43	dB Mode
7	dB Variance
3	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
13/07/15	14/07/15	15/07/15	16/07/15	17/07/15
55	53	55	52	56
78	73	72	81	76
39	39	43	42	43
57	53	55	52	56
43	41	30	43	38
7	6	5	7	6

Day Time V Night Time (db) Readings			
	12	dB Average (Mean)	increase
	8	dB max	increase
	0	dB min	increase
	12	dB Mode	increase
N/A		dB Variance	
	4	dB Standard Deviation	increase



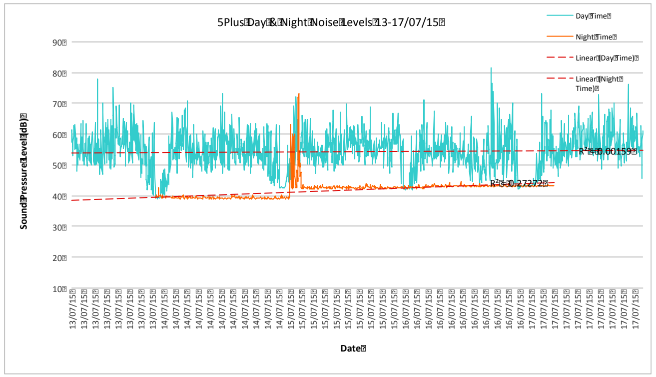


Fig. 194 - 5Plus Environmental (Noise) Tabular and Graphical Seasonal Data (Summer)

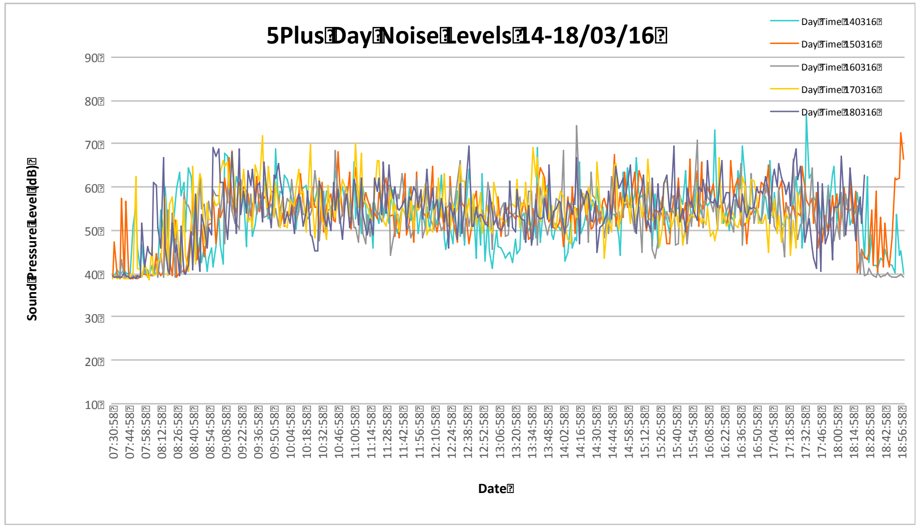
5Plus 14-180316

Day Time (db) Readings	
54	dB Average (Mean)
77	dB max
39	dB min
54	dB Mode
44	dB Variance
7	dB Standard Deviation

Night Time (db) Readings	
40	dB Average (Mean)
65	dB max
38	dB min
39	dB Mode
2	dB Variance
1	dB Standard Deviation

Day Time Readings				
Mon	Tues	Wed	Thurs	Fri
14/03/16	15/03/16	16/03/16	17/03/16	18/03/16
53	54	52	54	55
77	72	74	72	69
39	39	39	39	39
55	56	39	53	51
53	54	52	54	55
7	6	7	7	7

Day Time v Night Time (db) Readings			
	14	dB Average (Mean)	increase
	12	dB max	increase
	0	dB min	increase
	14	dB Mode	increase
N/A		dB Variance	
	5	dB Standard Deviation	increase



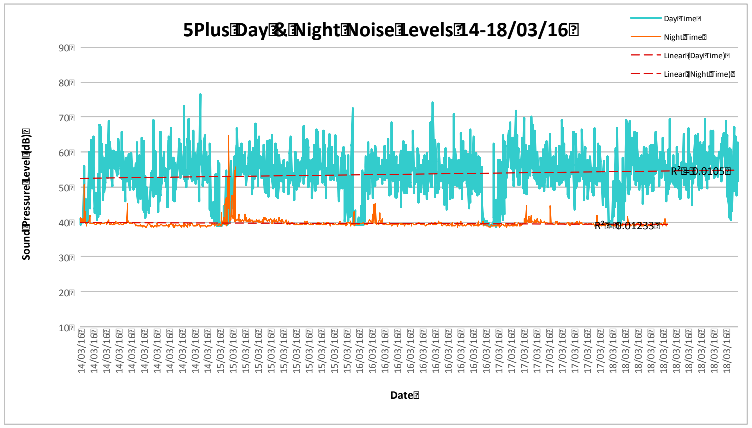


Fig. 195 - 5Plus Environmental (Noise) Tabular and Graphical Seasonal Data (Spring)

6.6 Statistical Data Review

One of the fundamental aspects of the research was to assess the relative correlation between physiological factors and the impacts imposed by the workplace and to what extent feedback could be achieved. Detailed with Fig's. 195-202 are indicated graphically via scatter plots the independent variable relationship between key IEQ aspects. The IEQ aspects have been selected from the survey responses to manage the data presentation and have been applied to (x2) volunteers, (x1) from BSRIA and (x1) from 5Plus. Both are female and have provided consistent empirically derived data. The sensory vest has not been utilised as detailed previously.

Statistical (Regression) Analysis								
Season	Agent	Factor	Noise		CO_2		Temp' deg.C	
			(***r***)	(***p-value***)	(***r***)	(***p-value***)	(***r***)	(***p-value***)
Winter	CH	GSR	0.106	0.117	0.098	0.1450	0.246	0.0002
		Skin Temp'	0.169	0.012	0.565	6.56E-20	0.172	0.010
	MA-H	GSR	0.033	0.561	0.130	0.0241	0.130	0.024
		Skin Temp'	0.130	0.024	0.585	6.52E-29	0.719	5.81E-49
Autumn	CH	GSR	N/A		0.699	9.7E-47	0.138	0.014
		Skin Temp'			0.726	7.11E-52	0.531	5.76E-24
	MA-H	GSR	0.214	0.0001	0.253	9.07E-06	0.484	4.81E-19
		Skin Temp'	0.054	0.349	0.300	1.14E-07	0.216	0.0001
Summer	CH	GSR	0.190	0.0007	0.094	0.098	0.606	1.87E-32
		Skin Temp'	0.009	0.879	0.189	0.0008	0.633	5.04E-36
	MA-H	GSR	0.497	4.28E-20	0.119	0.0385	0.102	0.077
		Skin Temp'	0.373	2.42E-11	0.499	2.9E-20	0.466	1.34E-17
Spring	CH	GSR	0.133	0.026	0.621	1.16E-30	0.751	5.4E-51
		Skin Temp'	0.096	0.109	0.212	0.0004	0.531	2.22E-21
	MA-H	GSR	0.257	6.3E-06	0.244	1.96E-05	0.093	0.108
		Skin Temp'	0.153	0.007	0.200	0.0004	0.237	3.36E-05

Table 61 - Regression + ANOVA Test for Significance

The results of the regression analysis are presented for (x2) individuals only, but are presented to cover seasonal changes as indicated within the environmental data analysis. The factors used to assess correlation are CO_2, temperature and noise, with physiological factors utilised being skin temperature and GSR. Heart rate and breathing rate were not utilised due to lack of data confidence.

The results of the statistical analysis offer little correlation between sites and although much of the data is significant the relationship between the variables would not suggest any significant relationship exists. There is however, some evidence to suggest that GSR and CO_2 are somewhat related in a number of instances, but nothing to suggest any level of consistency. The Graphical representation would also support this view.

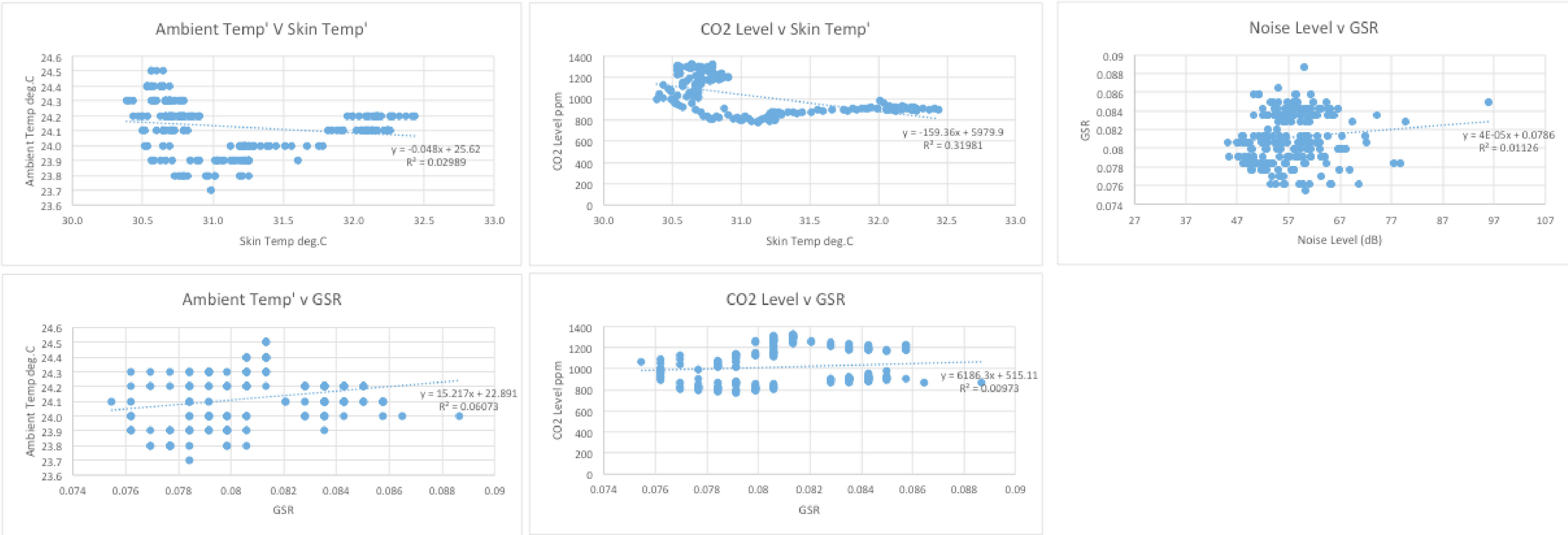


Fig. 196 - 5Plus CH 12/12/16 Ambient v Physiological Response Correlation

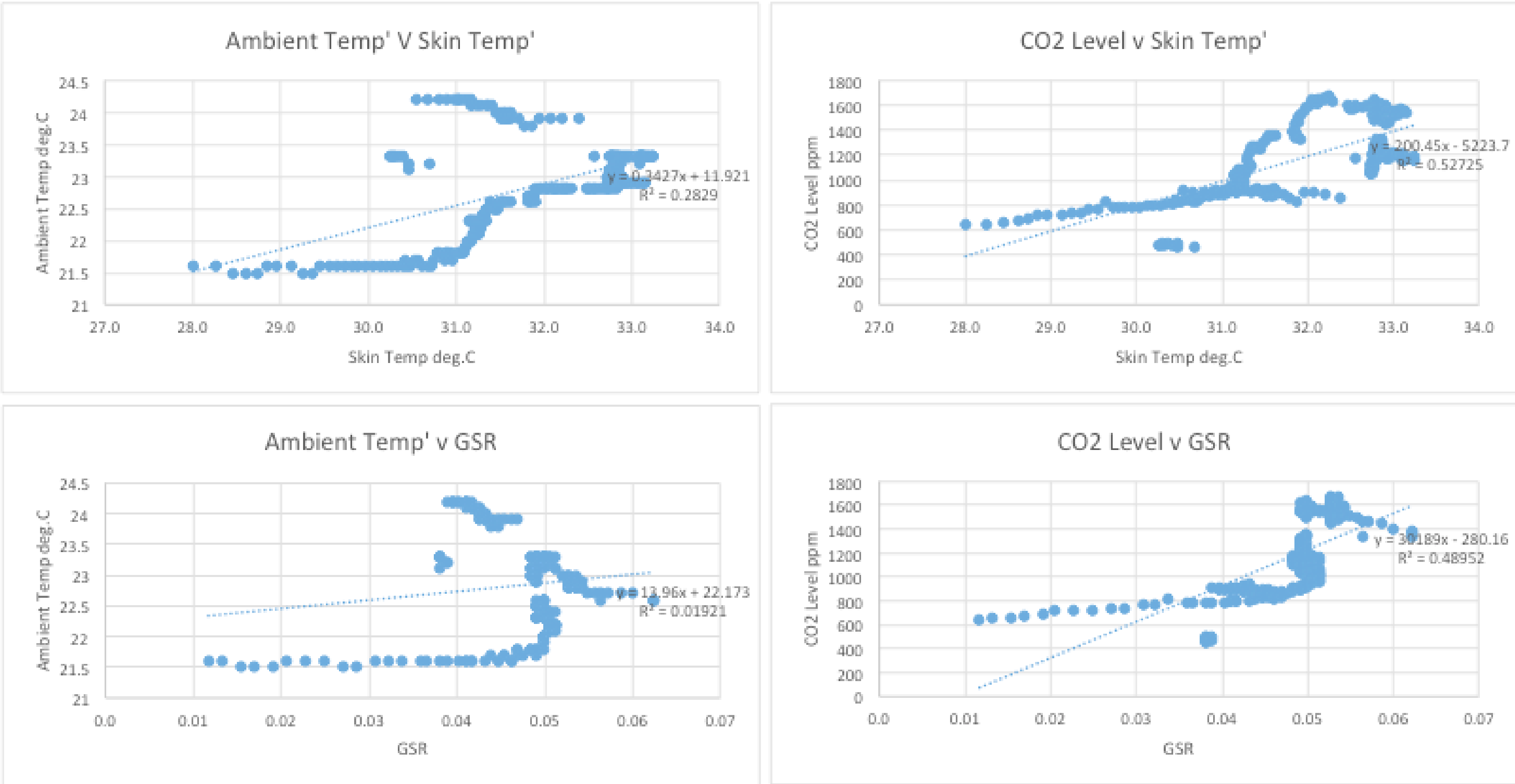


Fig. 197 - 5Plus CH 18/11/15 Ambient v Physiological Response Correlation

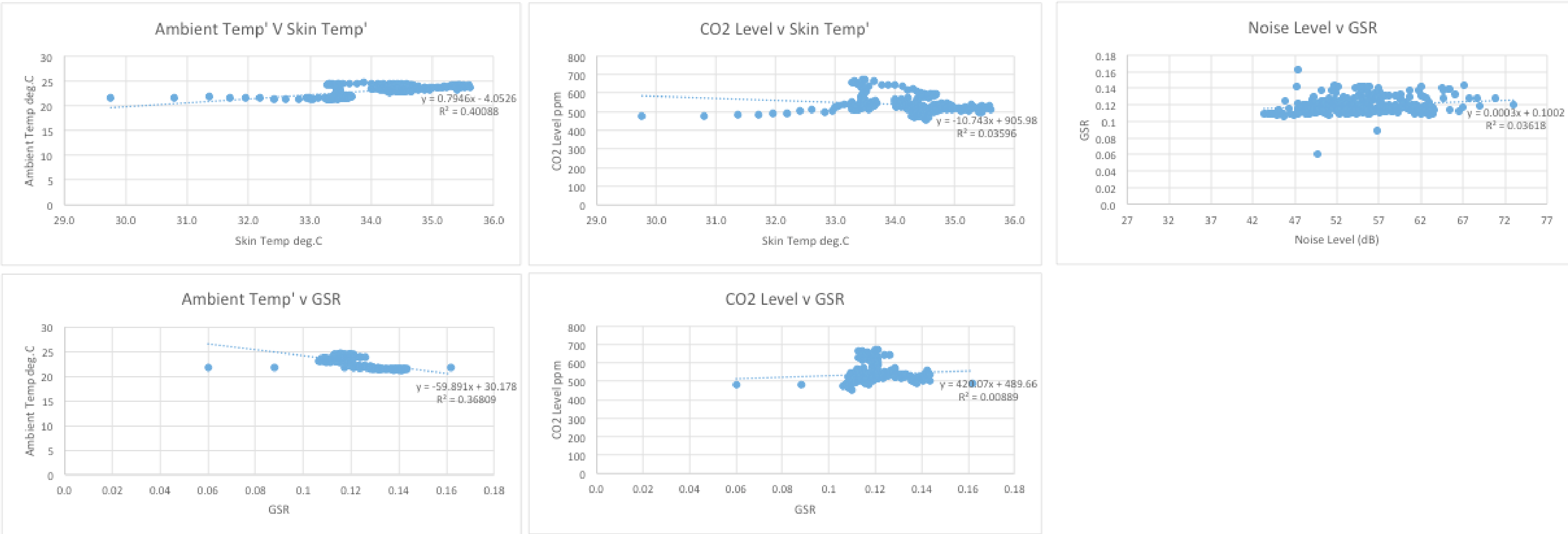


Fig. 198 - 5Plus CH 14/07/15 Ambient v Physiological Response Correlation

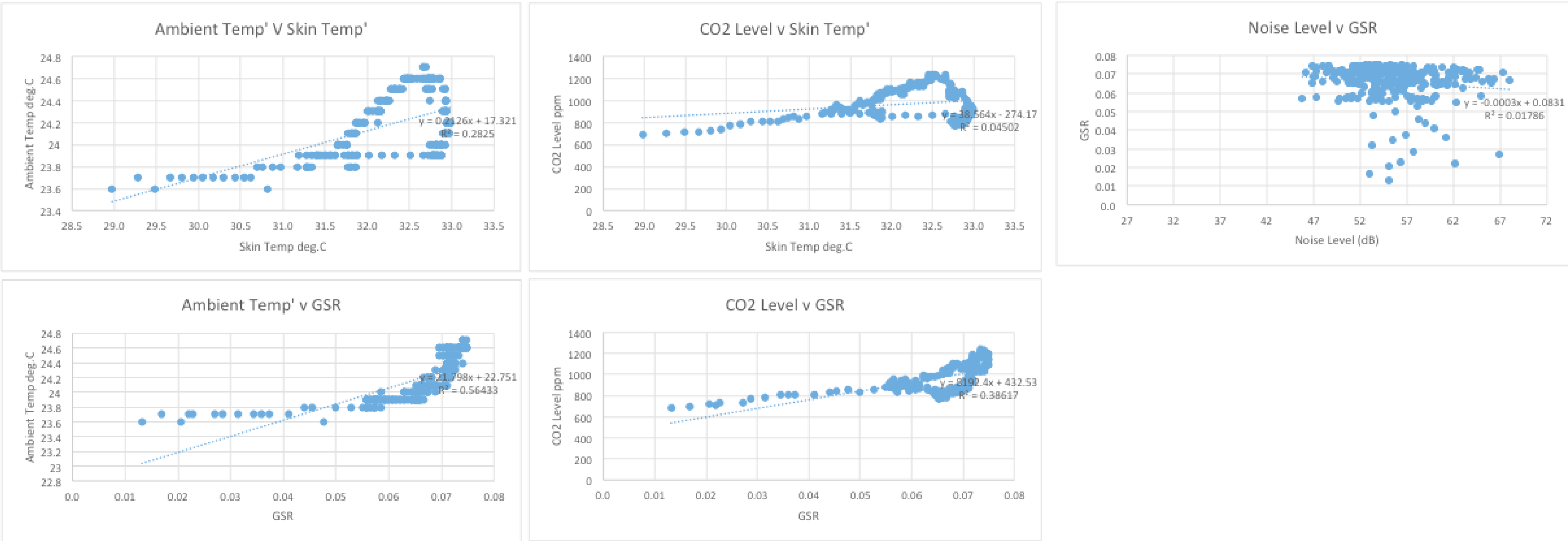


Fig. 199 - 5Plus CH 15/03/16 Ambient v Physiological Response Correlation

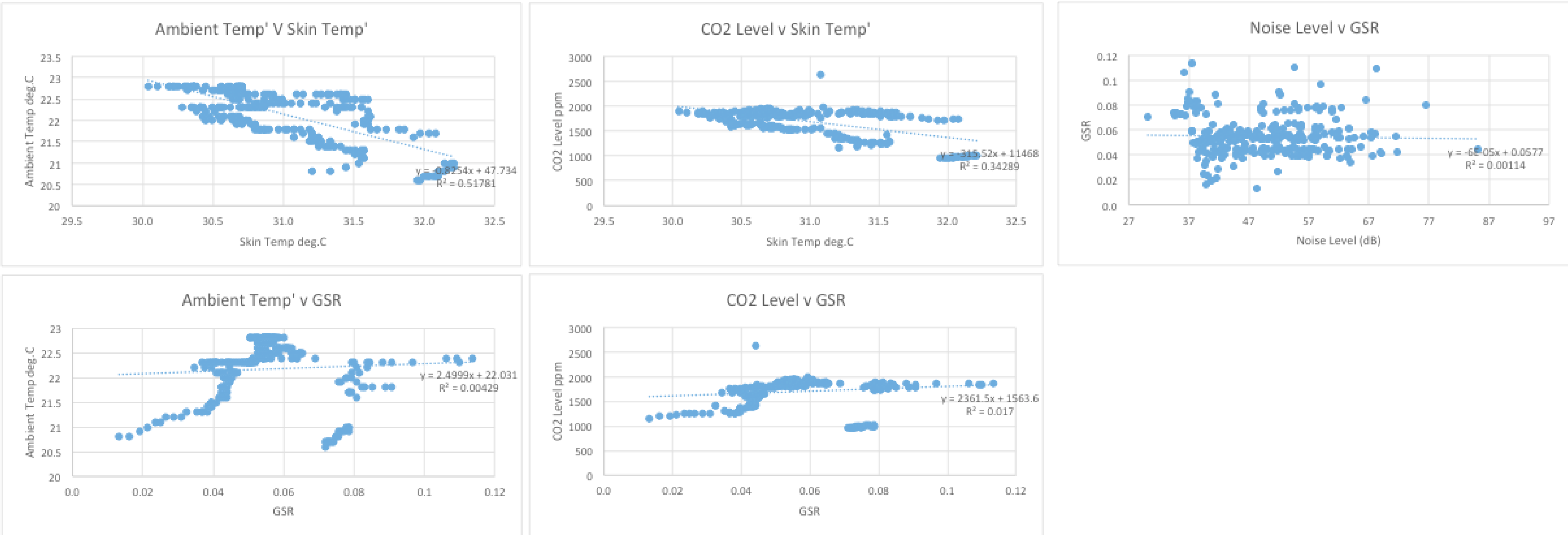


Fig. 200 - BSRIA MA-H 06/12/16 Ambient v Physiological Response Correlation

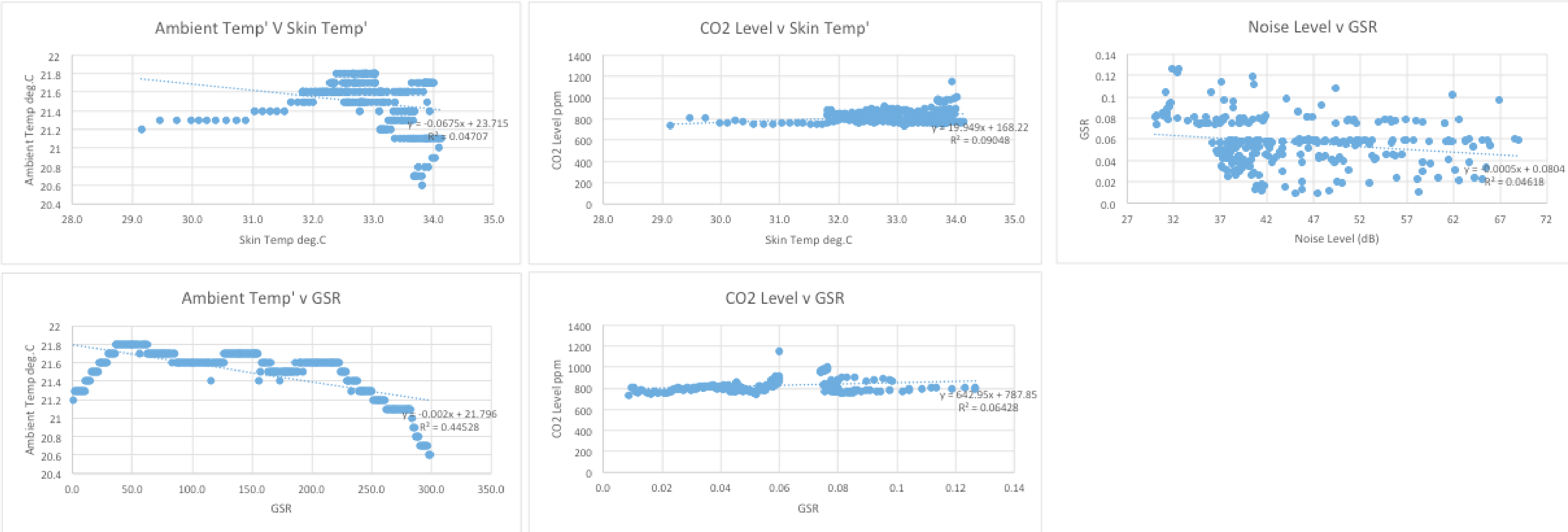


Fig. 201 - BSRIA MA-H 16/09/15 Ambient v Physiological Response Correlation

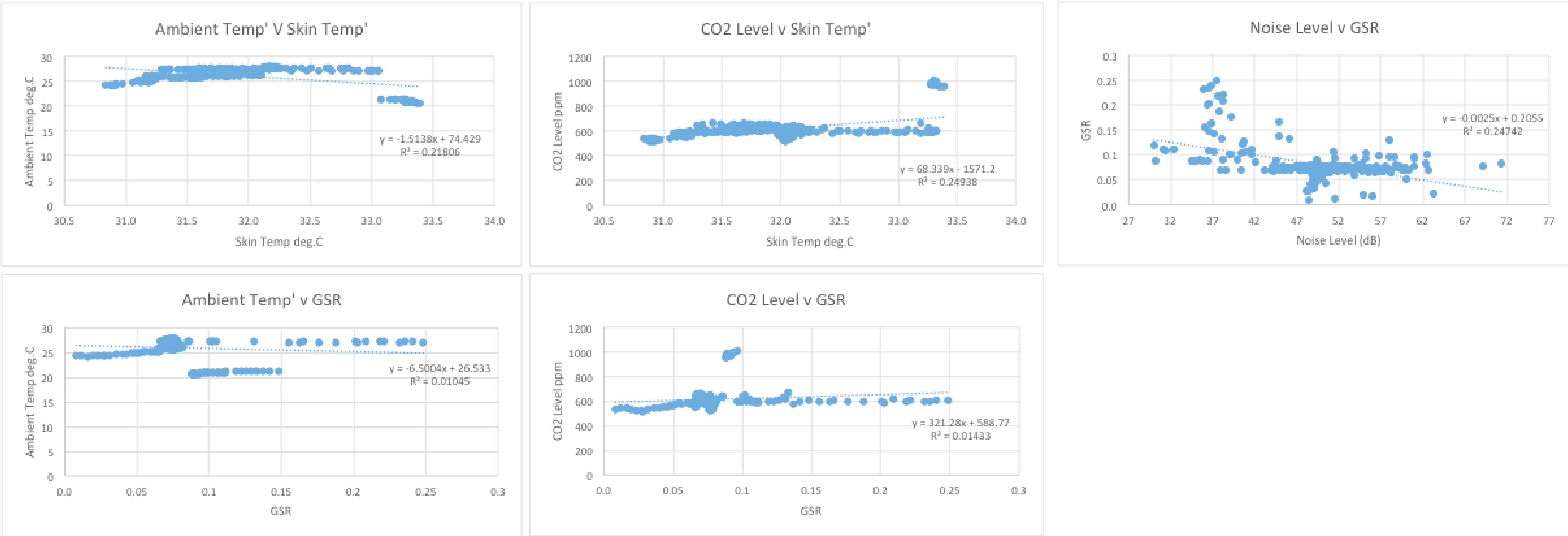


Fig. 202 - BSRIA MA-H 16/08/16 Ambient v Physiological Response Correlation

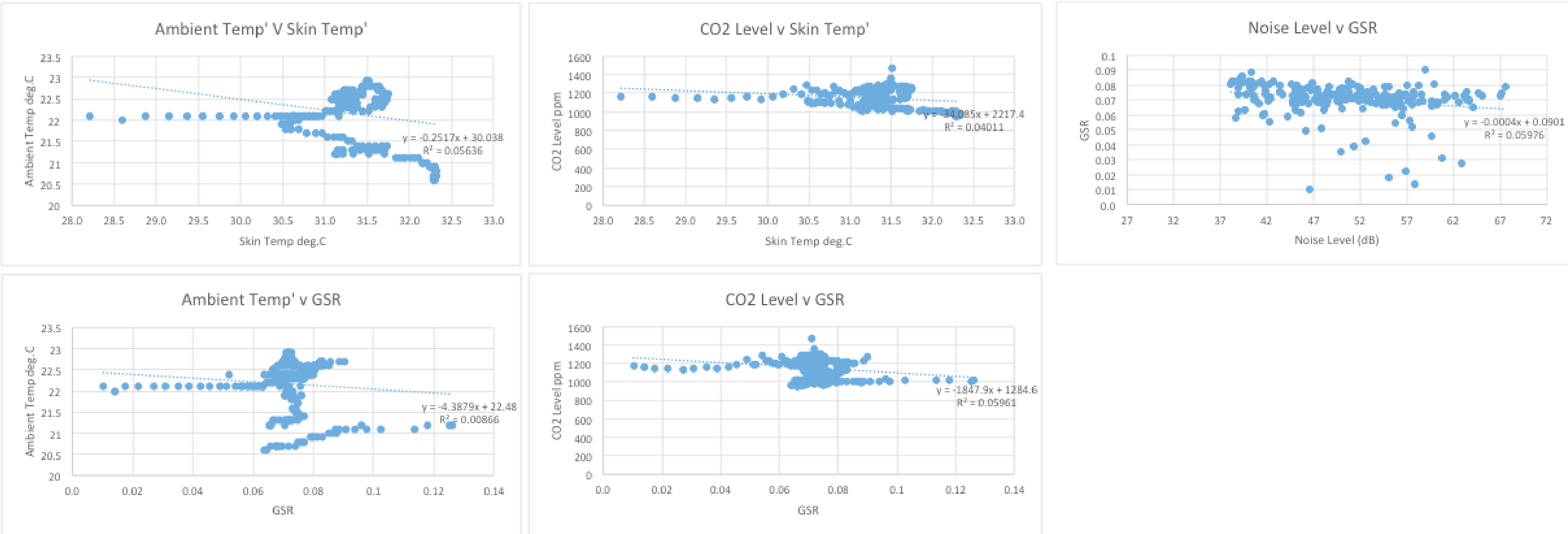


Fig. 203 - BSRIA MA-H 26/04/16 Ambient v Physiological Response Correlation

6.7 Chapter Summary

The empirical environmental data was useful in confirming how the spaces were performing, and from the assessment made, we are much clearer in terms of issues being experienced.

The nature of each space is very similar, but certain nuisances as discussed earlier have been confirmed. It has been proven that Noise and IAQ (CO_2) are particular issues that should be addressed to improve the performance of the spaces. From the survey responses Noise, IAQ and thermal comfort were particular issues, but it is only noise and IAQ to which we can empirically support.

Noise, temperature and CO_2 are directly related to occupancy, therefore it is interesting to note the back ground levels (day-night) and to what can be achieved when the building is empty to reduce the CO_2 threshold ahead of occupation, With regards to temperature night time purging or sealing the building, this may be an option to reduce temperatures in summer and increase temperatures in winter, and Noise data may be useful to trend, facilitating occupant knowledge exchange. If historical data is available then it may be possible to predict quite zones and advise occupants.

With regards to correlating any relationship with the selected key independent variables, both physical and environmental, there is little evidence to suggest that any true correlation exits. The ANOVA and regression analysis Table 61 supports this view.

The seasonal assessment also offers no further correlation opportunity and therefore the aim of proposing that physiological feedback is a realistic step forward to improve performance and to provide consistent correlated data is perhaps unfounded at this time.

Chapter 7 - Research Discussion

7.1 Introduction

This chapter discusses the impact of indoor environmental quality factors upon occupant physiological performance and how potentially to create an enhanced post occupancy evaluation model linking IEQ factors, occupant physiological factors and individual subjective POE responses. This research based upon (x2) naturally ventilated workplaces, sought to define further existing research and to offer guidance to next steps or further consideration.

7.2 Research Methodology Summary

Based upon previous similar research concepts and methods described within Chapter 2, this research utilised four (x4) discreet methods to assess and review the selected research sites at BSRIA and 5 Plus Architects. These are detailed within Chapter 3 Fig. 36, but are summarised below:

1. Analytic Hierarchy Process assessment of IEQ Factors.
2. Post Occupancy Evaluation Techniques
3. Semi-Structured Interviews
4. Site Measurements – Physiological & Environmental.

The research being conducted across (x2) geographically displaced sites was a significant research challenge, but has offered some unique insight in terms of occupant performance similarities, similar IEQ deficiencies and male/female differentiation of certain physical responses.

7.3 IEQ Factors & Performance

Within many commercial buildings, thermal conditions are not well controlled. Sappenen & Fisk (2006) discovered statistically that occupant performance values increase between the values of 20-23^{o}C, yet decrease with temperatures >23-24^{o}C. Concluding that a quantitative relationship between IEQ factors, health and productivity differs between temperatures and buildings, it is important to see each workplace as a unique interactive space. It is also recognised that responses to IEQ improvements will have different effects for each individual within their unique environments, and also as a consequence of the type of work being conducted. It is also important to note, that IEQ improvements may combine, and therefore it becomes difficult to assess which improvement contributed to any increase in performance.

Within the (x2) sites monitored, it has been found that it is indeed very difficult to assess the impacts and contributions of IEQ factors as stated by Sappen & Fisk. The results obtained on the whole would support this view, however, within this study, defining the minimum and maximum level of productivity is very difficult. This consideration drove the approach to focus upon performance rather than productivity, as it was more easily defined and measured.

Based upon REHVA Guide No.6 and research by Leyton and Kurvers (2010), their study concluded that a relationship did in fact exist between workplace thermal performance, IAQ, ventilation rate, productivity and absenteeism. The research cannot confirm these relationships, however, it can be suggested that that thermal performance, IAQ and ventilation CO_2 have a direct impact on the occupants subjective perception of the space they occupy.

7.4 IEQ Factors and Controls

The importance of thermal comfort is reflected by Liu et al (2014) as a means of interacting with IEQ factors and by adapting to the conditions through building interaction. Liu supports the theory of Nicol, Humfreys and Roaf (2012) that the adaptive approach to comfort is based upon a simple control principle; "if a change occurs so as to produce discomfort, then people will react in different ways to restore their preferred comfort level". It is proposed therefore that adaptation may be used to influence building and human performance to drive energy efficiency, however, Liu et al (2014) adds, that by using intelligent feedback systems the possibility of integrating the building with occupant comfort factors and their subsequent behaviours, this approach will actually drive energy efficiency and occupant comfort. The POE surveys conducted through this research, would support these views, however, this is a consequence of the occupant becoming the sensory agent to make a direct change, either by moving to a quieter zone or opening or closing a window etc. The issues to which research volunteers found great difficulty dealing with, was the unknown or un-perceived factors such as IAQ. As an example, CO_2 at both sites was a major seasonal issue, noted during semi-structured interviews and confirmed only through measurement.

The SMODIC model (Chapter 2 - Fig. 14) - **sm**art sensors, **o**ptimum **d**ecision and **i**ntelligent **c**ontrol derived by Yao and Zheng (2010) supports the work by Liu. Taking workplace IEQ data, occupant responses and applying a multi criteria decision-making process (MCDM), we begin to see how we could connect the building to the occupant. This objective model emphasised the point, that occupant adaptation within the workplace requires interaction with workplace IEQ factors, and if we are to minimise the conflict between occupant comfort and energy efficiency, then we need to measure and interpret building and occupant data. The research at both BSRIA and 5Plus Architects would support this view. The issues and responses noted would suggest that occupant and building feedback would be a very useful satisfaction factor, but controllability should be strictly limited.

7.5 Building & Occupant Integration

Monitoring people smartly to reduce energy consumption has in the past been the primary rationale for attempting to connect occupants, their behaviours and their expectations to the building. Using the premise that if occupants are informed about their energy footprint they can then adjust their behaviour (Darby 2006), then this principle could be adopted to influence the performance of IEQ factors by using occupant information sent back to the building systems (Spataru and Gauthier 2014).

It was subsequently recognised, that both physiological and environmental sensors were also necessary in order to obtain the relevant IEQ and occupant empirical data, with Andersen et al (2008), suggesting that by delegating indoor environmental controls to the occupant, this increases the difficulty of predicting building performance. However, if as Agha-Hossien (2015) suggests a link does exist between occupant behaviour and building energy consumption, it is therefore important to understand these relationships discretely. To some extent this research supports these views, however the empirical data and difficulty in obtaining accurate relative data has caused some concern as to the ability of modern BMS systems to cope with such data transfer and processing.

As discovered, to assure reliability of the data it needs to be cleansed and processed before using, and as a consequence physiological data can be unreliable if not validated. A form of artificial intelligence may therefore need to be part of any next steps. Occupant psychological impacts as well physiological effects, and the stressors derived from the work task cannot in most circumstances be defined or event timed which can also effect data acquisition. Delineating these different tasks is very difficult real time, and certainly difficult within a dynamic naturally ventilated building without a very large amount of expensive monitoring equipment and significant intervention.

7.6 Intelligent Better Buildings

The emergence of Intelligent Building (IB) principles is now seeking to create a relationship between the building and its occupant, the main features identified by Kell (2005) as six key building attributes:

7. IEQ factors are automated in some respect.
8. Posses integrated, informative and responsive adaptive systems
9. Rely upon passive intelligence to replace unnecessary active systems
10. Integrated occupant intelligence enabling direct occupant connectivity
11. Organisational intelligence integrates the building capability and its potential
12. Intelligent space management exists to adapt to changing business needs

Kell (2005) emphasises that a common factor associated with IB's is that they focus more towards the use of information to improve performance and to increase value to any organization rather than the occupant, and our own research would concur. Looking at the possible links between IB's and human integrated intelligence, Hinanen (2004) proposed that several possible artificial components existed;

5. Integrated functional connectivity offering the occupant personal control and/or information exchange.
6. Building self recognition a state of conscious state of awareness
7. Adjustable technology and building services
8. Embedded sensory logic to monitor the building occupant - kinaesthetics - *the study of body motion, and of the perception (both conscious and unconscious) of one's own body motions*

Our research would support Hinanen's view particularly concerning building self-recognition and the awareness of the environment to which we occupy. Most survey respondents suggested some control would be useful, however more importantly, the awareness of what was happening within the space would be extremely useful. If data could be defined and managed to provide a boundary framework for each occupants physiological performance matched to historical IEQ performance, then at least we will have connected some awareness of the physical realties of occupying a workplace.

Well-being and the intelligent work environment proposed by Reijula (2011) proposes that the intelligent work environment must interact with and between users. Survey responses within our own research supports this view, however, well-being is little understood or translated to occupants to enable them to understand the principle of well-being. Perhaps a solution lies in educating occupants across IEQ factors and well-being, and in facilitating them access to data so they can for themselves see how they are preforming real time e.g. GSR, body temperature, heart rate within any given workplace.

7.7 Dynamic Relationships

The Comfort of workers in office buildings: the European Hope project, defined "comfort" as being part of the term of health and was defined as; "*the indoor environment can be defined as healthy when the combination of its physical, chemical and biological properties are such that they do not cause illness, and that they can provide a high level of comfort for the intended activities of the occupant".*

The qualitative research approach supports this view, the responses obtained particularly concerning glare and CO_2 the invisible properties, clearly articulated health & well-being are related. Were –ve IEQ factors occur they may not be visible, however, their affects can be quite debilitating and cause reduction in task performance. The IEQ measurements at BSRIA support this statement, as claims of lethargy were immediately connected to an IAQ issue and linked to seasonal building operations i.e. windows closed and no mechanical supplementary ventilation. Not known at the time however, but through empirical data feedback we are now able to alert occupants to poorly preforming spaces they may wish to avoid. The HOPE project concluded, and further recommended, that physiological monitoring is a key factor for understanding the relationships between buildings and occupants, and that it would be a significant step forward in developing effective workplaces (Bluyssen et al 2011).

The research has uncovered the real dynamics of connecting occupants to the built environment. The amount of data to be handled, the reliability of the data and the technology available is not yet mature enough to build a functioning intelligent system. The approach therefore may be a staged approach, by first defining what we should measure, and then how we should feedback the data and to what purpose will it be used.

7.8 IEQ Factor Standard Development

In reviewing existing research, it is relatively clear that many personal and physical interactive aspects exist to cause an impact to the building occupant. The separate approaches of occupant satisfaction, well-being, productivity, happiness, motivation, performance each has a different definition and meaning. Research has yet to decide which if at all any of these approaches are a suitable metric that can be taken forward into an enhanced POE model, and although some of these approaches are inter-related, they perhaps need to fit within a hierarchy of needs to enable the overall feeling of well-being to become the adopted rated metric.

A review of IEQ standards proposes that no single IEQ standard specifically towards defining an accepted performance metric, either for the building, occupant or the workplace. It was also noted that global differences exist between accepted technical standards as do Regional differences, but it is clear that a standard model could be developed to rationalise the many subjective definitions. Additionally it would be useful to determine a globally accepted performance metric and to clarify what is actually needed to subjectively and objectively analyse workplace performance.

Reviewing POE tools and models there are simply too many differing types available some offer benchmarking solutions and others offer investigative or diagnostic options. Each specific building assessment will be different, consequently the selection of POE tool is extremely important, however, the key element to any POE is the nature of the output and to what use the POE results will be utilised. Most POE surveys are cross sectional at a point in time, longitudinal surveys take up time and are disruptive, so a new approach may be required using future technology and within todays and future intelligent buildings.

The development of an enhanced ePOE model requires the assessment of existing research, and development of new IEQ standards. Recognising that the objective physical environment and occupant physical responses may need to combine into an active feedback model, we need to agree what actually can be connected. If by connecting the occupant as a sensory agent to the building, and by the occupant understanding more intimately their workplace environment, then an opportunity may exist to affect the overall subjective feeing of well-being. Providing data that is part of a defined common standard will actually reinforce the information as credible and provide both subjective and objective responses that can be tied together.

7.9 Review of the Applied Surveys

Some of the more interesting feedback during the interviews was the general acceptance that the workplace was secondary to completing the task and that integrated feedback would be useful. The changing nature of work and the places work is conducted is fundamentally changing, through hot-desking, causal spaces and the tasks being performed becoming more ICT supported. Workplaces should just be spaces with minimal conscious impact to allow the task to be performed.

The key aspect associated with this research confirms occupant and building bi-directional connectivity with empirical feedback would be extremely useful. However, there is some real concern at the ability of current BMS to successfully mange this task given the complexity of the integration across many demands and systems. At the system, protocol and inter-connectivity level of building devices, this will need to be fundamentally addressed to allow such functionality to exist. In addition the ability of systems to affectively control multiple occupied spaces all with specific individual requirements is seen as a major obstacle as no protocol or mature models are currently proposed. A keep it simple principle is essential to maintaining good quality buildings. If we over complicate the building controls, the likelihood is it will fail and subsequently IEQ factors will become a major issue.

The measurement, control and management of illness from bacteria, virus and “bugs” is something very little attention has been offered currently. More attention seems to be needed in this area and sufficient technology exists to contribute a solution, however, it is likely to be cost prohibitive unless additional tangible benefits can be realised e.g. energy savings, operational savings.

The key aspects noted within the surveys, concerned the typical recurring IEQ factors that constantly evade solutions, these being IAQ, Noise, and thermal comfort. In addition the surveys also noted that peak performance and fatigue occur generally in the morning and afternoon respectively. The application of IEQ technology and feedback to the occupant may therefore be a step forward in allowing this information to assist decision-making and to look at the causation of fatigue particularly, whether energy or IEQ related. We have seen that GSR tends to reduce over the week (Mon-Fri) in the majority of cases, however, daily values can and do increase & decrease. The individual effects will therefore need to be historically adjusted and analysed prior to using in any workplace design approach.

The factors of the three main evaluation metrics, IEQ, OP, WQ are 0.595, 0.183 and 0.222, indicating that of the three factors the IEQ is the major factor. The global priorities of all the sub-factors linked to the main factors, thermal quality and lighting quality are identified as the two most significant sub-factors according to the results. Occupants' activity within the workplace to avoid a sedentary existence would appear to be the most important OP factor to be monitored. The most significant sub-factor relevant to WQ would appear to be sufficient workspace so as not to feel over-crowded. The use of activity and Metabolic Equivalent have been limited in research within the built environment, its importance in translating this back to individual may be useful in assessing a sedentary existence. We need the building to talk to the occupant advising them of a "state of being". When we consider the difficulty of applying previous POE studies even if administered electronically, they all need to be managed. We will always have this challenge, but if we can define a standard, we will then only need to develop a means to measure the important factors rather than assess every parameter as detailed within the Berkley Instates IEQ assessment model (Table 6 Chapter 2)

This research can be assumed a preliminary study given the limited number of respondents, however, the output would appear consistent with other previous research. Using two different qualitative methods and one mathematical quantitative technique has proven the general perceptions of SME's and occupants to be similar in comprehension. What was important to understand within this research, was the premise that connecting people to the building is a core aim, and by understanding what priorities occupants and designers place on various factors, it will assist in providing this connectivity. Interesting that OP factors have scored consistently lower in importance which is again consistent with the qualitative surveys results. This research proposes that IEQ factors should be significantly promoted as a future performance need, allowing occupants to understand IEQ factors and their affects empirically. This is supported by Kano's Satisfaction Theory and work by Kin & de Dear (2012) in respect of +ve and –ve IEQ relationship mapping.

7.10 Sensory Monitoring Results

Previous physiological; studies tended to be based around chamber defined experiments (Fanger 1972; Zheng, Chen et al 2006 Li, Li et al 2010 each proposing skin temperature varies with changes in the ambient thermal environment. Although these and many studies were conducted in ideal thermal chamber conditions, this research has focused upon free running naturally ventilated spaces.

Recent studies Liu (2012) and Keeling (2016) have utilised real workplaces to measure and analyse individual responses, but not over such an extensive time period. The daily, weekly and seasonal approach adopted within this research is considered to be a unique approach, however certain issues have been uncovered in this approach.

The FM industry needs to focus upon understanding the fundamental issues of monitoring the human physiological responses within occupied work environments, and to understand how data may be interpreted and used. The effects of the built environment are experienced through the senses and controlled via the brain, therefore, being within a real time work environment all the senses (Clements-Croome 2007) can be said to be contributory to measured values. The issue today however, is how to harness this level of experience and to translate it digitally.

Yun and Steemers (2008) and Chen and Hwang et al (2011), concluded that occupant behaviour and physiological responses are time-dependant, and where the occupant experiences a thermal transition, the response is noted in changes to skin or near body temperature that create opposite changes in heat flux average. GSR values and response would also support a time-dependant correlation particular at the start and end of the day. GSR values generally appeared at both sites daily and weekly to follow a downward trend Monday to Friday, however, with certain exceptions. The RE understands this in the main to be work related or around lunchtime. GSR profiling would suggest that daily profiles could not be considered similar for each individual, however, trending between +/- values to an agreed standard may be a significant opportunity to allow measured data to be benchmarked. Our research supports these views, but further wider more exclusive research will be required.

Table 56 summarises the research values and provides evidence similar to Liu (2012) that seasonal relevance for skin temperature average values across all volunteers at BSRIA were extremely close, with only 0.7deg.C difference across each individual and season. 5Plus average values were slightly more at 3.51deg.C however, the average value between sites concludes only a +/-1% difference between sites.

GSR values were extremely low and required scientific notation to assess their real value. As a key stressor and variable parameter, GSR is perhaps the most interesting time-dependant parameter to view. The significant aspect noted was the inability to define impacts simply looking at the digital data, this being an issue for assessing IEQ impacts.

7.11 IEQ Factor Monitoring

The nature of each space is very similar, but certain nuisances as discussed earlier have been confirmed. It has been proven that Noise and IAQ (CO_2) are particular issues that should be addressed to improve the performance of the spaces, however, it was the way daily and weekly CO_2 values that were observed which need to be considered ahead of the next seasonal change in date.

Noise, temperature and CO_2 are directly related to occupancy, therefore it was interesting to note the background levels (day-night) and how the night time threshold set the daily level prior to occupancy. Background CO_2 levels within an enclosed space were very interesting. Establishing the minimum level over night set the daily starting point ahead of occupation indicating whether the day may or may not be a high CO_2 day. Similar to weather predictions, if we can link historical performance data to expected occupation levels, we could predict IEQ factors to advise occupants of their forthcoming workplace conditions.

With regards to temperature night-time purging or sealing the building, this may be an option to reduce temperatures in summer and increase temperatures in winter but this will need to factor other IEQ factors as noted above. Noise data may be useful to trend, facilitating occupant knowledge exchange, but difficult to assess ahead of occupation due to its dynamic nature. If historical data is available then it may be possible to predict quite zones and advise occupants, but this would only be a guide based upon past data, however similar in principle to CO_2 predictions.

The seasonal assessment across the selected parameters offered no significant correlation and therefore the aim of proposing adaptive physiological feedback as a realistic step forward to improve performance and to provide consistent correlated data is perhaps some way off at this time. Although many propose connectivity models, the practicalities of applying theses are yet to be resolved inclusive of setting standards. This research supports previous research and has concluded similar results, but now proposes that within the dilemma for improving performance that perhaps focus towards setting a defined standard and disseminating its content to building occupants will improve awareness and subsequently well-being. Only at that point can the industry rise to the challenge of developing an application and system integration to feedback IEQ and Physiological performance values in discrete ways.

Chapter 8 – Conclusion & Further Research

8.1 Research Objectives

The primary aim of this research was to assess the impact of indoor environmental quality factors to enable an enhanced post occupancy evaluation model (ePOE) to be created. This new ePOE approach was to consider linking IEQ factors, occupant physiological responses and subjective perceptions within the office workplace, enabling the occupant and workplace to be connected together.

The research questions being answered are noted below:

Q1 - Which IEQ factors have an impact upon occupant physiological performance?

Q2 - How to measure and interpret the affects IEQ factors place upon the occupant?

Q3 - How to prioritise IEQ factors to promote health, well-being & performance?

Q4 - How to adopt real time IEQ & physiological data to inform building occupants?

The three key objectives were assigned to achieve the research aim and these are detailed below;

Objective 1- "develop a building and occupant relationship framework describing the importance of health & well-being within the office workplace"

Objective 2 – "using empirical physiological responses obtained from the building occupant, assess the relationship of IEQ and physiological factors"

Objective 3 – "to understand the importance of IEQ factors for building occupants and for those who design, construct and operate buildings"

The research also focuses upon the real issue of how practically to measure IEQ and occupant physiological factors and considers the actual needs of the occupant and to how best to consider connecting the occupant to the building.

8.2 Research Objective 1 – Occupant Relationship Framework.

This research considered the extremely wide subject area of IEQ factors and their relationship between building occupants and the workplace in which they work. Chapters 1 & 2 considered the issues facing the UK FM Industry and the relevance and provision of existing research, seeking to clarify the many components associated with IEQ factors and the relationship with building occupants. Form this review, Fig. 11 (Chapter 1) was developed by the R.E to encapsulate a framework idea of IEQ factors ahead of moving into a review of existing standards.

The development of an enhanced ePOE model required the assessment of existing research, application of existing IEQ standards and the knowledge that existing POE's are different and therefore may need to be challenged. Recognising that the objective physical environment and occupant physical responses need to combine into an active feedback model, (x2) survey techniques were adopted as detailed within Chapter 4 to create a feedback framework of needs and issues across both occupants and SME's.

The research has highlighted the existing traditional issues and confirmed them to remain current, however, interpreting further we can acknowledge the following insights at both BSRIA and 5Plus Architects which appear consistent with existing industry feedback;

1. Improving fresh air knowledge, awareness and affordability should provide subjective improvements in satisfaction, wellness, well-being & performance.
2. Development of integrated and robust feedback and control systems is essential if we are to connect the building and occupant effectively.
3. Improvement in standards, interoperability and guidance documents.
4. Defining IEQ factors and driving better knowledge exchange and awareness.
5. Overall agreement for connecting the building and occupant together.
6. Noise remains a significant issue to solve by better architectural design.
7. Thermal comfort although understood is still a key issue to manage.
8. Indoor air quality needs to be defined, understandable and affordable.
9. A need to address airborne contaminants has been previously ignored.
10. IEQ factors need to be mutually connected to create a better workplace.

These feedback points suggest the basis for the framework indicated within Fig.11.

8.3 Research Objective 2 – IEQ & Physiological Factor Relationship.

The main findings and observations of this chapter are noted as follows:

1. GSR would appear to be time dependant around certain periods of the day and indicate continuous sharp increases and decreases consistently throughout the day.
2. GSR values rise sharply at the start of the day and follow simple profiles for each volunteer subject to periods of work related or time dependent events.
3. The large majority of GSR trends indicate a downward trend from Mon-Fri.
4. GSR profiles of individuals at both sites can be considered similar.
5. A discrete difference in GSR value exists between male & female volunteers.
6. Skin and near body temperature are closely related due to sensor location.
7. Skin temperature rises constantly during the day around the expected value of approx. 24deg.c despite daily and seasonal temperature differences.
8. Skin and near body temperature changes appear to be environmental dependant and not time dependant and achieve an opposite reaction in Heat Flux average during transient response to change.
9. Heat flux average is not suitable as a measuring parameter due to method of calculation and measurement, and location of the sensor.
10. A seasonal consistency exists across all measured average values.
11. Arrival, occupancy and departure phases do appear to have relative affect upon measured values, but this could be due to device normalisation.
12. Within what was considered to be a relatively stable internal environment there is no discrete evidence to suggest transitional seasonal changes exists across any of the measured values.
13. The two sites provided similar average values and performance within reasonable tolerances, this could be developed and used within building feedback system using predictive artificial intelligence.
14. Breathing rate and heart rate provides limited conclusive output.

15. Blood oxygen monitoring is not considered a suitable or robust measured parameter due to difficulty in measuring through available devices. Accuracy is also not vey good due to sensor technology and wear ability issues.
16. It is difficult to assess the causation of transient events due to work task or emotional stress, and therefore the empirically measured data can only be considered as time specific within a real life operational situation.
17. The armband technology would appear a more robust method of measuring the necessary parameters in comparison to the limited sensory vest.
18. The use of volunteers proved difficult to motivate, and therefore some form of wider study may help in establishing additional data.
19. The use of the sensory vest proved exceedingly difficult due to battery life and wear ability. Female participation was rejected and male use proved uncomfortable within a sedentary daily work environment over a period of hours. Using the R.E as a sensory vest wearer was not ideal due to location within the research space.
20. Affects of clothing did not form part of this study as they have covered in previous work, but there is an acceptance that certain extraneous elements are relative to this research.

A number of issues were discovered in undertaking this element of the research;

1. The sensory vest was not a suitable measurement device.
2. The amount of data was excessive and required extensive cleansing.
3. Although current at the time technology has improved dramatically.
4. Wireless data transfer was sometimes an issue.
5. Volunteers were patient but sometimes not in good health.
6. Different clothing types may have distorted values.

Although a significant amount of data has been collected and analysed, consideration should be given to extending such a study and to consider additional sites with additional individuals. The consistency and significance of results within similar site ambient environments, would suggest additional review would be useful in confirming the validity of this research.

8.4 Research Objective 3 – Importance of IEQ Factors.

The output from the AHP study indicated IEQ, OP, WQ are 0.595, 0.183 and 0.222, indicating that of the three factors IEQ is the major factor. The global priorities of all the sub-factors linked to the main factors, thermal quality and lighting quality are identified as the two most significant sub-factors according to the results. Occupants' activity within the workplace to avoid a sedentary existence would appear to be the most important OP factor to be monitored. The most significant sub-factor relevant to WQ would appear to be sufficient workspace so as not to feel over-crowded.

This part of the research can be assumed a preliminary study given the limited number of respondents, however, the output would appear consistent across the semi-structured interview and on-line POE responses. Using two different qualitative methods and one mathematical quantitative technique has proven the general perceptions of SME's and occupants to be similar in comprehension. What is important however, is to understand within this research however, is the premise that connecting people to the building is a core aim and by understanding the priorities occupants place on various factors will assist in providing this connectivity. Interestingly the OP factors have scored consistently lower in importance again consistent with the qualitative surveys results. This research proposes that IEQ factors should be significantly promoted as a future performance need, to allow occupants to understand IEQ factors and their affects.

The AHP element provided an expected conclusion and this was used to assess the IEQ factors ay analyzing their relationships. Statistical analysis found no real relationship between the various independent actors and within the naturally ventilated environment. These results therefore do not support adaptive feedback response to be available for adoption.

8.5 Conclusion.

The overall conclusions across the various research elements are detailed as follows:

1. Connecting the occupant to the built environment is seen as a next step in the evolution of building systems.
2. Building systems will need to improve exponentially to accept the levels of feedback data which could be generated.

3. A new IEQ global/regional standard should be developed ahead of technology development.
4. Any standard to assess what and how measurements should be achieved.
5. Within a naturally ventilated free running environment it is very difficult to assess whether impacts and/or causation are linked.
6. There is no statistical evidence to support a direct relationship exists between factors within the research environment.
7. Sensory and IEQ factor performance feedback would be extremely useful in providing occupant awareness to their surroundings.
8. How to connect the individual through system protocols will need to be developed.
9. Building and occupant feedback Yes – Occupant control No. A clear message from occupants and SME's.
10. The physiological parameters measured need to have a discrete relevance to the occupant, otherwise it becomes a meaningless exercise. The parameters to be measured and exchanged need to have a purpose.
11. Real time data transfer would not provide an adaptive response opportunity, therefore the proposal would be to use the data as a predicative assessment tool for noise, thermal comfort and CO_2 management.
12. IAQ remains misunderstood across both occupants and SME's and which fundamentally needs to be addressed. The high seasonal results were unknown at both sites as they were not measured or fed-back to the occupant, hence impacts were experienced.
13. Seasonal average differences between the sites offer an opportunity to extend the research to assess if regional variations would be acceptable.
14. Soft-Landings and POE should be a combined process to achieve a pre and post set of IEQ factor measurements. This would then generate future predictive data calculations by creating daily (day-night) values, weekly and seasonal values to understand how the building is operating and to what impacts it may present to occupants within the building.
15. Activity, and energy expended can be monitored and used to calculate energy into the environment.

In summary we can as engineers make things work, but making systems reliable and effective is sometimes more of a challenge. Let's keep it simple and feedback only what is seen as an agreed standard and actually useful to the building and the occupant. A predicative rather than adaptive approach to feedback is probably the next step, giving the occupant time to make a decision. If you think of the daily morning weather bulletin, this is the R.E's recommendation; a dashboard of daily potential IEQ factor figures informing the occupant of possible impacts based upon historical, threshold and current values.

8.6 Contribution to Knowledge

The main areas contributing to existing knowledge is as follows:

1. Within a free running naturally ventilated real time environment, this research supports existing IEQ assessments and POE models.
2. The use of occupant sensory physiological equipment has successfully been demonstrated and analysed.
3. Skin & Near Body temperature and GSR can be used to inform the building systems and occupant if required.
4. The GSR trend in the majority of cases has been confirmed as a downward trend Mon-Fri indicating a psychological assessment is now required.
5. Delineation exists between male and female physiological results.
6. Daily and seasonal data modelling is a necessity to enable buildings and occupants to successful understand how they are performing.
7. There is no evidence of direct correlation between measured IEQ and physiological parameters.
8. Existing BMS technology has been found to be unable to deliver such feedback systems.
9. Noise and CO_2 measured data could be structured as key feedback metrics to inform a predicative occupant dashboard model.

Although no new novel system, model or method of calculation has been derived, this research has proven the need for such feedback systems and for that need to be based upon an agreed set of global standards.

8.7 Proposed Future Work

This research has been conducted using a limited budget and access to available sites, and therefore a recommendation to achieve greater levels of data across many other sites needs to be a consideration to support this research. Technology has advanced significantly since the start of this research project e.g. the smart watch; sensor materials etc., therefore future research should also consider current available technology.

The development of a regional IEQ standard focussing upon the needs of occupants and operators, and to consider system capabilities is seen as a next step to achieving system integration.

The development of an appropriate sensory, IEQ ICT model and data exchange platform is also vitally important if the industry is to create a reliable resilient and integrated BMS feedback system.

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Appendix – A

SCME Ethics Approval Application Form (Students – BSc/MSc/EngD/PhD)

All students conducting research using human subjects, human samples (however obtained) or human personal data are required to obtain ethical approval prior to the start of their data collection. ***Students not conducting research of this nature are required to provide a NIL RETURN by checking the Nil Return box below and signing. It is compulsory for all students to submit an ethics application, even if it is with a Nil Return. A supervisor must sign off a Nil Return.***

Please read carefully the briefing notes appended to this form (pages 6-8). You must complete this form with your Supervisor. ***You cannot start data collection until you have received supervisory level approval.*** **It is strongly advised that you seek ethical approval two weeks prior to data collection to allow time for sign off.**

Note to Supervisor: the check list on page 4 must be completed prior to sign off. If you are unsure about the nature of the project and wish to pass the form to the SREC for approval then please complete section 5.

The final electronic version must be submitted to the SCME School Research Ethics Committee (SREC) at scme-ethics@lists.reading.ac.uk. This is the preferred method; if you wish to submit a paper version please put it in an envelope marked FAO SCME SREC and send it c/o Linda Holland, Room 312, Engineering, Whiteknights.

NIL RETURN:

☐ I confirm that my research does not involve: research with human subjects, human samples (however obtained), human personal data, access to company documents/records, questionnaires, surveys, focus groups and/or other interview techniques

Name & email address of student

Gary Middlehurst – [redacted]

Signature of student

Date:

28/04/15

Revised post comments from ethics committee review 28/04/15

Student No: 16027087

Title of Proposed Project:

The physiological effects of indoor environmental quality factors in determining a sustainable approach to future commercial office design & operation.

Name and email address of supervisor

Prof. Runming Yao – [redacted]

Signature of supervisor

Date:

28/04/15

SECTION 1: PROJECT INFORMATION

1. Project Details

Date of submission: 28/04/15

Student No: 16026087

Title of Proposed Project:

The physiological effects of indoor environmental quality factors in determining a sustainable approach to future commercial office design & operation.

1.1 Responsible Persons

Name & email address of student

Gary Middlehurst – [redacted]

Date: 28/04/15

Name and email address of supervisor

Prof. Runming Yao – [redacted]

Date: 28/04/15

1.2 Nature of Project (please X as appropriate)

Undergraduate ☐ Masters ☐ EngD/PhD ☒

1.3 Sample size (if appropriate) 300 - <400

1.4 Expected duration of project (months) 12 (months)

1.5 Are any of your subjects below 18 years of age? Yes ☐ No ☒

1.6 Brief Summary of Proposed Project and Research Methods.

The project seeks to understand the impacts of the internal built environment upon workplace occupants across various workplace types. The research will focus upon a number key Indoor Environmental Quality (IEQ) factors created by the workplace environment and the impact these factors have upon occupant physiological performance, and how these elements relate to occupant well-being. Four workplace sites have been secured in London (x1); Manchester (x1); Reading (x1) and Bracknell (x1). Workplace monitoring at (x4) discrete locations using metal 1.9m Environmental Monitoring Poles (EVP's) will be mounted adjacent 4 selected volunteer desk positions encompassing Temperature, Humidity, CO_2 and Illumination sensors installed as detailed within ASHRAE Guide 55. The monitoring will be continuous 24x7 for a 12-month period with each of the 4 sites monitored for (x4) 5-week periods to incorporate each annual season. Specific monitoring periods are detailed within the accompanying research programme Ref: GM/RP/R2/040315. In addition to the EVP's installed at each desk location (x4) selected volunteers at each workplace are requested to wear physiological measuring equipment as supplied by Sensewear Inc. and Hidalgo Ltd. The physiological monitoring will assess the occupant's physical state of well-being over each daily period including travel to and from the workplace. The Sensewear monitoring devices take the form of an armband device monitoring Galvanic Skin Response, Metabolic Rate (calculated), Heat flux, and Skin Temperature. During each monitoring period, the Hidalgo Equivital sensory vest will be worn by (x1) occupant (within the group) on a rotating basis. This device, will provide

SECTION 2: PROJECT SCOPE

2.1 Please answer ALL of the following questions concerning your proposed research:

		Yes	No
1.	Are the participants and subjects of the study patients and clients of the NHS or social services to the best of your knowledge?	☐	☒
2.	Are the participants and subjects of the study in any way unable to give free and informed consent within the meaning of the Mental Capacity Act 2005 to the best of your knowledge?	☐	☒
3.	Are you asking questions that are likely to be considered impertinent or to cause distress to any of the participants?	☐	☒
4.	Are any of the subjects in a special relationship with the applicant?	☐	☒
5.	Does your project pose any risk to either yourself or the participant?	☐	☒

If you have answered **YES** to **any** of the above questions, or are **unsure**, please contact your supervisor.

2.2 Please answer ALL of the following questions concerning your proposed research:

		Yes	No
1.	Arrangements for expenses and other payments to participants, if any, have been considered. Participants will not be paid and will act as volunteers, however, they will be encouraged to return survey information for a charity donation made by the EngD research engineer of <£350.00 max.	☒	☐
2.	Participants **will be**/have been advised that they may withdraw at any stage if they so wish. See accompanying forms Appendix C page 14.	☒	☐
3.	Issues of confidentiality and arrangements for the storage and security of material during and after the project and for the disposal of material have been considered. Each volunteer will be allocated a number, names will not be published. Storage of all data will be encrypted with password protection known only to the research supervisors and the TSBE centre manager. Data storage will be restricted to the research engineers UoR network and no data will be stored any other drives or USB memory drives. The only exception to this rule concerns electronic survey data, which will be stored on a secure survey tool developed by Bristol University (BOS) and managed via an agreement, governed under the UK Data Protection Act. Upon completion of the project all data will be provided on a secure password protected USB device to allow transfer of the data to the research engineers UoR network account. All data will be deleted by Smart Survey Ltd and from the USB upon completion of the research. Weekly Physiological data will be transferred between monitoring devices, secure UoR laptop and UoR network domain.	☒	☐
4.	Arrangements for providing subjects with research results if they wish to have them have been considered. All survey results will be provided in the form of a detailed report upon request. Physiological results will be provided to the research volunteers upon request.	☒	☐
5.	The arrangements for publishing the research results and, if confidentiality might be affected, for obtaining written consent for this have been considered. Appendicx C – page 14 (11)	☒	☐
6.	Information Sheets and Consent Forms had been prepared in line with University guidelines for distribution to participants. See Appendices.	☒	☐
7.	Arrangements for the completed consent forms to be retained upon completion of the project have been made. A secure data file will be created and stored by the UoR SCM TSBE Centre.	☒	☐
7a.	Please outline arrangements for retention of consent forms Forms will be scanned and stored on the University of Reading IT Network and password protected. A dedicated filing system will be developed and utilised for the storage of all participant forms. All paper forms, details and print-outs will be destroyed via shredding upon completion of each phase of the research.		

If you have answered **NO** or you **cannot confirm** the answer to **any** of the above questions, contact your supervisor.

WHAT TO DO NEXT

Student research projects must be checked by the supervisor (section 3) and signed-off (section 4) before submission to the SCME SREC for reference only. If submission to the SREC is required, supervisors must complete section 5 and submit to the SREC for approval. *Data collection can only commence once supervisory or SREC approval has been given.*

SECTION 3: APPLICATION CHECK LIST FOR SUPERVISORS

Please tick to confirm that the following information has been included and is correct.

Please indicate (N/A) if not applicable

Information Sheet for participants **YES** **N/A**

Includes student's name and contact details
☒ ☐

Includes supervisor's name and university contact details
☒ ☐

Includes statement that participation is voluntary
☒ ☐

Includes statement that participants are free to withdraw
☒ ☐

Includes reference to the ethical process
☒ ☐

Includes reference to disclosure
☒ ☐

Includes reference to confidentiality, storage and disposal of personal information collected
☒ ☐

Is written in clear (grammatically correct) English in lay terms
☒ ☐

Consent forms for participants
☒ ☐

Other relevant materials

Questionnaire/Survey (with relevant heading requesting informed consent)
☒ ☐

Interview Schedule (questions for semi-structured or open ended interviews)
☒ ☐

Advertisement/leaflets used for recruitment of research participants
☒ ☐

Letters used for recruitment of research participants
☒ ☐

Other (please specify) - Research Programme detailed and provided.

Physiological monitoring device OEM data sheets provided.
☒ ☐

Supervisor (print name) Prof. Runming Yao **Signature**

Date 28/04/15

☒ I confirm that an Information Sheet and a Consent Form have been prepared and will be made available to all participants. These contain details of the project, contact details of the student and advise subjects that their privacy will be protected, their participation is voluntary and that they may withdraw at any time without reason.

☒ I confirm that research instruments (questionnaires, interview guides, etc) have been reviewed against the policies and criteria noted in The University Research Ethics Committee Notes for Guidance. Information obtained will be safeguarded and personal privacy and commercial confidentiality will be strictly observed.

☒ I confirm that **all** related documents, including any questionnaires, interview schedules and copies of the Information Sheet and Consent Form, are attached and submitted with this application.

SECTION 4: SIGN-OFF BY SUPERVISOR

I hereby approve data collection for the purposes of this research project.

Signed:

(Supervisor) Date: 28/04/15

(Student) Date: 28/04/15

SECTION 5: SUPERVISOR SUBMISSION TO SCREC

This submission requires approval by the SREC.

Signed:

(Supervisor) Date: 28/04/15

(Student) Date: 28/04/15

SREC

Date received:

This application is approved/not approved (please add reasons for rejection below)

(SREC member) Date:

End of Application Form

SCME Ethics Approval Application Form
Briefing Notes

INTRODUCTION

The University of Reading has a strong commitment to ethical practice in the research conducted by its students, researchers and academic staff. This is managed by the University Research Ethics Committee (REC). Full details can be found on the University website: http://www.reading.ac.uk/internal/res/ResearchEthics/reas-REethicshomepage.aspx

Whilst these SCME Briefing Notes provide all the information required to complete the SCME Ethics Approval Application form, your attention is also drawn to the University REC Notes for Guidance which can be found by following the link http://www.reading.ac.uk/web/FILES/reas/EthicsGuidance.pdf. These notes provide additional guidance on University policy, and the criteria for research instruments.

THE SCME SCHOOL RESEARCH ETHICS COMMITTEE (SREC) AND ITS REMIT

All students conducting research with human subjects and data are required to obtain ethical approval prior to the start of their research. Applications from students on taught programmes will be approved by their supervisor, who will act on behalf of the SREC. **Students should seek ethical approval two weeks prior to data collection. Unless requiring approval by the University REC, students can proceed with their data collection once they have received supervisory level approval.**

If a supervisor has ethical concerns over the proposed research they will submit it to the SREC for further review.

Applications which need to be processed at the School level will be reviewed by two members of the committee. Applicants will be notified of the Committee's decision as quickly as possible (within 10 working days). Approval means that the Committee raises no objections to the project on ethical grounds. The SREC does not assess either project viability or scientific value. Staff and researchers must await SREC approval before proceeding.

Applications which cannot be processed at the School level must be approved by one member of the SREC and signed off by the Head of School, before being submitted to the University REC for approval. **Under these circumstances you will need to fill out the University REC Project Submission Form in Appendix A.** Applications that are rejected may be revised and resubmitted, but students must **NOT** begin research on projects that have been rejected.

EXCEPTION CASE CATEGORIES

According to the *University Research Ethics Committee Notes for Guidance*, the School can approve applications which:

- do not involve participants who are patients or clients of the health or social services (unless such participation is purely for the purposes of audit);
- do not involve subjects whose capacity to give free and informed consent may be impaired within the meaning of the Mental Capacity Act 2005;
- do not involve questions that might reasonably be considered to be impertinent or likely to cause distress to any of the participants;
- do not involve any element of risk to the researchers or participants;
- do not involve subjects in a special relationship with the researcher.

If your project falls into any of these categories, your project must be referred to the University REC. This will be done via the SCME SREC. In this instance, please speak to your supervisor.

BASIC PRINCIPLES

Ethical considerations enter into the choice of research topic, negotiation of access to people and organisations, data collection, data storage, data analysis and reporting. Projects requiring ethical approval often need a little work to make sure that all relevant issues are included and that the presentation is clear and concise.

The basic principles of ethical research include:

- Informed Consent – participants should have the opportunity to make a free, informed decision as to whether they wish to participate in the research study or not. This depends on giving them as much information as necessary to make an informed decision.
- Professionalism and integrity – being honest about the purpose and content of the research and behaving in a professional, respectful manner at all times. This includes the idea of reciprocity; namely, that research should be of mutual benefit to both researchers and participants. It also involves making sure that data is not used for any other purposes than those agreed upon with the participants.
- Protection from harm – being aware of and minimising the risk of harm to the participants and researchers, where harm includes embarrassment, stress, physical discomfort and/or harm to individuals' personal and professional lives (including career prospects and future employment). This includes making sure that issues relating to confidentiality and anonymity are discussed beforehand and respected. It also involves leaving participants the option to refrain from answering certain questions and to withdraw at any stage in the research.
- Confidentiality – making sure that the names and identities of participants are kept secret, unless you have written permission to disclose them. This depends on masking personal and organisational identities.
- Data Protection – this builds on the UK 1998 Data Protection Act. It ensures that personal data should only be obtained for the specified purpose, be relevant and not excessive, be processed lawfully and fairly and not be kept longer than necessary.

PERSONAL SAFETY

The ethics procedure also takes account of the safety of the researcher as well as the participants. You should take care not to disclose personal contact details, and in particular you should not make available your personal or mobile phone numbers but instead provide your University of Reading email address. Particular care should be taken when working alone or outside of the normal business environment and working hours and when using observation or recording techniques that may arouse interest or concern from members of the public.

Your supervisor should be made aware of the means whereby your participants are to be enrolled in the research project; the active approach of participants without forewarning is unlikely to receive approval without discussion of the arrangements for the safety of the researcher (for example, approaching respondents in a shopping mall in order to complete a questionnaire. In this case it would be appropriate to have another student on hand and to have identification immediately available).

PROCEDURE AND GUIDELINES FOR COMPLETION

All students must complete this form, even if it is only with a nil return. Note that ethical issues may arise even if the data is in the public domain and/or it refers to deceased persons. If a student believes that their project requires review by the SCME SREC they should discuss this with their supervisor, who will sign the form before passing the submission on to the SREC.

All relevant sections of this form must be completed. **This form must be signed by a supervisor before data collection can proceed.** If in the course of the research the nature of the project changes, supervisory advice should be sought. **A copy of the approved page of your ethics form must be included in your final project.**

Final electronic versions must be submitted to the SCME School Research Ethics Committee (SREC) at [redacted] for monitoring purposes. Forms should include electronic (scanned) signatures from the Supervisor and the student. If this is not possible, applicants should submit a signed hard copy of the SCME Ethics Approval Application Form to:

FAO SCME SREC
c/o Mrs Linda Holland,
School of Construction Management & Engineering
Room 312 Engineering Building,
Whiteknights,
P.O. Box 225,
RG6 6AY.

A completed project submission for the SCME SREC must include:

- SCME Ethics Approval Application Form
- Information sheet (or equivalent)
- Consent form (or equivalent/ email trail)
- Questionnaires or interview schedules

Forms can be found in the appendix. Blue, bold, italicised text must be amended/deleted as required. A recruitment poster template is available for use if you wish and can be found on Blackboard.

IMPORTANT NOTES

1 There is an obligation on all students and academic staff to observe ethical procedures and practice and actively bring to the attention of the SCME SREC any concerns or questions of clarification they may have.

2 Records of applications will be maintained and progress monitored as required by the University REC, overseen by the SCME SREC.

3 The SREC application form is designed to conform to the University's requirements with respect to research ethics. Approval under this procedure does not confirm the academic validity of the proposed project.

4 The Supervisor must complete the Checklist on page 4 of this form to ensure that all the relevant steps have been taken and all the appropriate documentation has been appended.

5 If you expect that your application will need to be reviewed by the University Research Ethics Committee and if you would like the SREC to forward it on to the University REC directly, please complete the University REC Project Submission Form in Appendix A.

6 For a sample information sheet, please see Appendix B.

7 For a sample consent form, please see Appendix C.

8 For a sample survey/questionnaire heading, please see Appendix D.

Appendix A: Project Submission Form for the University Research Ethics Committee

Note: All sections of this form should be completed, including the checklist. Please continue on separate sheets if necessary.

Student:

Gary Middlehurst 16026087

School:

SCME TSBE Centre (EngD)

Title of Project:

The physiological effects of indoor environmental quality factors in determining a sustainable approach to future commercial office design & operation.

Proposed starting date: May 2015 – April 2016

Brief description of Project:

The project seeks to understand the impacts of the internal built environment upon workplace occupants across various workplace types. The research will focus upon a number key Indoor Environmental Quality (IEQ) factors created by the workplace environment and the impact these factors have upon occupant physiological performance, and how these elements relate to occupant well-being. Four workplace sites have been secured in London (x1); Manchester (x1); Reading (x1) and Bracknell (x1). Workplace monitoring at (x4) discrete locations using metal 1.9m Environmental Monitoring Poles (EVP's) will be mounted adjacent 4 selected volunteer desk positions encompassing Temperature, Humidity, CO_2 and Illumination sensors installed as detailed within ASHRAE Guide 55. The monitoring will be continuous 24x7 for a 12-month period with each of the 4 sites monitored for (x4) 5-week periods to incorporate each annual season. Specific monitoring periods are detailed within the accompanying research programme Ref: GM/RP/R2/040315. In addition to the EVP's installed at each desk location (x4) selected volunteers at each workplace are requested to wear physiological measuring equipment as supplied by Sensewear Inc. and Hidalgo Ltd. The physiological monitoring will assess the occupant's physical state of well-being over each daily period including travel to and from the workplace. The Sensewear monitoring devices take the form of an armband device monitoring Galvanic Skin Response, Metabolic Rate (calculated), Heat flux, and Skin Temperature. During each monitoring period, the Hidalgo Equivital sensory vest will be worn by (x1) occupant (within the group) on a rotating basis. This device, will provide additional medical grade Heart and Respiratory rates for analysis. Volunteers will be asked to wear the armbands and vest during travel to and from the office,

I confirm that to the best of my knowledge I have made known all information relevant to the

Research Ethics Committee and I undertake to inform the Committee of any such information which subsequently becomes available whether before or after the research has begun.

I confirm that if this project is an interventional study, a list of names and contact details of the subjects in this project will be compiled and that this, together with a copy of the Consent Form, will be retained within the School for a minimum of five years after the date that the project is completed.

Signed:

[ ] (Supervisor) Date: 28/04/15

[ ] (Head of school) Date: [ ]

[ ] (Student) Date: 28/04/15

1. This form is signed by my Head of School ☒
-
2. The Consent form includes a statement to the effect that
- the application has been reviewed by the University
- Research Ethics Committee and has been given a favourable
- Ethical opinion for conduct ☒
-
3. I have made, and explained within this application, arrangements
- for any confidential material generated by the research to be stored
- securely within the University and, where appropriate, subsequently
- disposed of securely. ☒
-
4. I have made arrangements for expenses to be paid to participants in
- the research, if any, OR, if not, I have explained why not. ☒
-
5. EITHER
   a. The proposed research does not involve the taking of blood
- samples ☒
- OR
   b. For anyone whose proximity to the blood samples brings a risk of

- Hepatitis B, documentary evidence of protection prior to the risk
- of exposure will be retained by the Head of School.

☐

Signed ____________________ (Head of School) Date ____________

6. EITHER
   a. The proposed research does not involve the storage of human
- tissue, as defined by the Human Tissue Act 2004:

☒

- OR
   b. I have explained within the application how the requirements of
- the Human Tissue Act 2004 will be met.

☐

7. EITHER
   a. The proposed research will not generate any information
- about the health of participants;

☒

- OR
   b. In the circumstance that any test reveals an abnormal result,
- I will inform the participant and, with the participant's consent,
- also inform their GP, providing a copy of those results to each and
- identifying by name and date of birth; See Appendix B.

☒

- OR

   c. I have explained within the application why (b) above is not
- appropriate.

☐

8. EITHER
   a. The proposed research does not involve children under the
- age of 5; ☒
- OR
   b. My Head of School has given details of the proposed research
- to the University's insurance officer and the research will not
- proceed until I have confirmation that insurance cover is in place.

☐

Signed ____________________ (Head of School)

Date ____________

This form and further relevant information (see University Research Ethics Committee Notes for Guidance, Sections 5 (b)-(e)) should be returned to:

Nathan Helsby
Secretary to the University Research Ethics Committee
Email: [redacted]
- **both electronically and in hard copy**

You will be notified of the Committee's decision as quickly as possible, and you should not proceed with the project until then.

Appendix B: Information Sheet

Student's name:	***Gary Middlehurst – Research Engineer***
Student's address:	***Tectona, Ongar Rd, Stondon Massey Brentwood Essex CM15 0EF***
Student Tel.	***07795 545843***
Student's e-mail:	***g.middlehurst@pgr.reading.ac.uk***
Student No.	***16026087***
Supervisor:	***Prof. Runming Yao [redacted])***
Supervisor Tel.	[redacted]

of indoor
performance

My name is ***Gary Middlehurst*** and I am an Engineering Doctorate (EngD) student within the Technologies for Sustainable Built Environments (TSBE) Centre here at the School of Construction Management and Engineering at the University of Reading.

I am conducting a research study into ***the affects various indoor environmental quality factors have upon the physiological performance of building occupants, and how in understanding these impacts workplaces can be designed to maximise space utilisation and to provide informed guidance upon occupant well-being within the modern office environment.*** I am particularly interested in ***understanding how the technical engineering infrastructure of the air-conditioning & ventilation systems, lighting systems, noise and indoor air quality impact human performance and to assess any impacts across a seasonal basis both within the workplace, during travel to and from workplace and at various rest periods evenings and weekends within the home environment.***

The research will be conducted over a 12-month period within your workplace environment and during your travel to and from home. We are therefore seeking 4 volunteers of any gender or age to participate in acquiring various personal physiological measurements through the use of wearable monitoring and sensory technology. Details of the equipment are provided via the www. links below, and a full explanation will be provided before the research commences enabling an informed decision to be made by the volunteer. A detailed research programme will be provided at the initial volunteer briefing session detailing the 12-month research programme and the rotating 5-week periods the volunteer will be asked to participate.

http://sensewear.bodymedia.com/site/sensewear/files/SW-brochure.pdf

http://www.equivital.co.uk/products/tnr/sense-and-transmit

In addition to the personal physiological measurements, the research will also monitor local indoor environment parameters adjacent your desk positions requiring the installation of an environmental monitoring pole mounted to your desk pedestal or desk. Details of the poles will be provided at the initial volunteer briefing session. Both the armband monitoring devices and sensory vest, will need to be worn over (x4) separate 5-week intervals, with each period arranged to capture each annual seasonal change i.e. Spring, Summer, Autumn and Winter. Full details of the rotation will be provided to selected volunteers at the initial volunteer briefing meeting.

As a final element of the research, the selected volunteers while wearing the monitoring and sensory devices during each 5-week period, will be asked each day (am/pm) to complete a short (5-min) electronic survey questionnaire relevant to their perceived well-being, and to encourage a response towards the existing workplace environmental quality factors. In addition to the electronic survey each volunteer will be further asked to participate in a semi-structured interview at the start and finish of each 5-week period where any feedback may be discussed. During these interviews I will ask you about your experiences during the previous 5-weeks and any specific issues encountered or notes. A number of structured environmental questions relative to the workplace environment will also be asked. A single (x1) electronic survey will also be conducted as part of further element of the research during the week-2, these responses will be used to consider the importance of workplace factors across a wider group within your organisation.

The following typical physiological limits are expected to be witnessed, but are not seen as absolute limits. The research engineer will make available at the end of each monitoring period a review of the measured data so the volunteer the may interpret their own physiological performance.

Heart Rate	*60 – 100 p/min*
Respiratory rate	*12 – 16 b/min*
Body temperature	*36-37 deg.C*
Blood Oxygen level	*96-99% (<94%)*

If you are willing to be interviewed, you will be asked to participate in an interview of about ***30*** minutes at the end of each 5-week period which will also form part of the research de-brief period. You can choose ***not to answer any of these questions or to participate in any phase of the research at any time, and y***ou are free to withdraw from the study at any time without notice.

At every stage, your identity will remain confidential, and your name and all identifying information will be removed from any written transcript. My supervisor and I will be the only people who will have access to this data, which will be stored on secure encrypted drives and additionally password protected. All stored data will be reviewed on a 6-month basis and deleted if not being used within the research. As part of the 1998 UK Data Protection Act you will have access to any data stored relative to yourself, which will be provided unhindered upon request.

With your permission should you participate in any interviews, I would like to ***record the interview and transcribe sections later for analysis and/or take notes. Copies of the transcript will be provided electronically using an agreed password and any requested changes will be made.*** The data will be kept securely and destroyed when the study has ended, which will be ***a maximum of 72-months/6-years from completion of research***. The collected and measured data will be used for academic purposes only.

Copies of the completed ***dissertation/report/publications*** will be available on request free of charge. If you have any further questions about the study, please feel free to contact me at the above address and contact details.

‘This project has been subject to ethical review here at the University of Reading, and in accordance with the procedures specified by the University Research Ethics Committee, and has been given a favourable ethical opinion for conduct’.

Print Name	
Signed	
Date	

Appendix C: Consent Form

Project Title: Workplace occupancy study to assess the effects of indoor environmental quality factors upon occupant well-being & performance

Consent Form

1. I have read and had explained to me by Gary Middlehurst (Research Engineer) the Information Sheet relating to this project and any questions have been answered to my satisfaction.

2. I understand that my participation is entirely voluntary and that I have the right to withdraw from the project any time, and that this will be without detriment.

3. I understand that my personal information will remain confidential to the researcher and their supervisor at the University of Reading, unless my explicit written consent is given.

4. I understand that my organisation will not be identified either directly or indirectly without my consent.

5. I agree to the arrangements described in the Information Sheet in so far as they relate to my participation.

6. Access to stored personal data will be provided upon request in a secure form without unnecessary delay. All measured data will be presented at the end of each monitoring period for the volunteers own personal review. The data will be presented in an easily presented and tabulated format.

7. I understand this research has been reviewed by the University Research Ethics Committee and has been given a favourable Ethical opinion for conduct.

8. I am aware the research is subject a Non-Disclosure Agreement between the University of Reading and The Royal Bank of Scotland (research funding) and I will keep all information and data issued to me securely and not to pass to any other 3rd party without the explicit consent of the University of Reading.

9. I will take responsibility for the equipment supplied to me as part of the research and advise of any issues which may cause injury or discomfort at the earliest opportunity.

10. I have been made aware that no financial inducements or payments are to be made to me as a volunteer as part of this research, however, I have been made aware that the research engineer will provide a charity donation of 10p per survey completed up to a maximum value of £350. The nominated UK charity will be at the discretion of the research engineer but made known upon request.

-

11. I am willing to proceed with the research in respect to the above and confirm my approval for any data to be used within this research project subject to it remaining anonymous.

Signed	
Organisation	
Print Name	
Date	

Appendix D: Electronic Questionnaire Survey & Semi-Structured Interview

The research will utilise two forms of data acquisition using both qualitive and quantitive question sets, administered using a twice daily 5-min electronically delivered questionnaire (am/pm), and through a 30-min semi-structured interview format at the start and end of each 5-week rotating monitoring period.

Semi structured interviews may be recorded with the prior consent of the research volunteer and a full transcript will be provided by the research engineer to the volunteer. Any amendments will be instigated by the research engineer without delay and presented for approval and sign-off. All interviews will be undertaken within the workplace at time convenient to the research volunteer.

During week-2 a single 15-min additional survey will sent to you via e mail link focussed upon specific elements of your workplace environment. This particular survey will used to assess the importance if indoor workplace factors and to associate any specific relationships with other collected survey and physiological data.

Our Electronic survey formats are scheduled below and will be delivered via an e mailed link to your desktop.

- This survey is part of a research study you have volunteered to participate and to which we thank you for your involvement, and which is being conducted by Gary Middlehurst, an EngD research student within the Technologies for Sustainable Built Environments Centre, at the School of Construction Management and Engineering located at the University of Reading, UK.
- Your decision to participate in this study is voluntary.
- You can stop at any time and are not required to complete all or any of the questions within any survey.
- Your participation will be kept confidential and your identification will be restricted to your allocated research volunteer No. which is securely and confidentially administered by the research engineer.
- Your identity and place of employment will not be mentioned within any publications and/or presentations resulting from this survey, unless explicit written approval is provided from yourself and/or your organisation.
- Submission of the survey indicates that you have agreed to participate in this part of the research study.
- If you have any questions, wish to request any personal data, incur any problems or concerns about this research or type of questionnaires, please contact in the first instance the Research Engineer:–

- **Gary Middlehurst** - [redacted] **or** by phone [redacted]

  or his supervisor:-

- **Prof. Runming Yao** – [redacted] or by phone [redacted] 8606

Thank-you for your valuable time, effort and patience in this leading class workplace research.

Survey Question and Interview Formats and Content - Example

To begin answering the questions please follow the on screen instructions – Thank-you.

Please insert your secure volunteer No issued to you via e mail into the box!

A list of questions will now be presented and should take no longer than 10-mins to complete the survey – Thank-you!

Please select the most appropriate answer to the following general questions:-

1. What is your gender – male; female.
2. Age – 18-25; 25-30; 35-40; 40-45; 45-50; over 50.
3. Country of Origin – select from drop down menu.
4. Travel time to and from the Workplace - <1hr; 1<2hrs; 2<3hrs >3hrs
5. Approximately have you taken any time off over the last 12-months
   - (1d; 2d; 3d; 4d; 1wk; >1wk; >2wk; >3wk)
6. If Yes to Q5 – please schedule the condition suffered.
   - (Cold/flue; Headaches; Muscular; Bronchial; sore eyes; nausea, other – (if other please describe in the text box) - Select multiple answers.)
7. What is your overall Feeling of Well-being – Poor; Good; V.Good; Excellent
8. Approximately how many hours are spent at your desk weekly – select amount of hours.
9. Does your desk, chair and general environment satisfy your workplace expectations – Yes or No.
   - (If No please briefly describe the issues in the free text box.)
10. How long have you worked for your organisation. Insert years

---

1 - If you were to describe your level of perceived thermal comfort today, where on the following scale would you position the indicator?

Select one answer.

- I generally like it - **Very Cold**
- Occasionally I like to be - **Cold**
- I would rather be - **Mildly Cool**
- Not distressed about being Warm or Cold - **Neutral**
- I would rather be - **Mildly Warm**
- Occasionally I like to be - **Warm**
- I generally like it - **Very Warm**

2 - How would you rate the overall Indoor Air Quality (Ventilation) within your workplace today?
Select one answer.

- Very Fresh, Clean and Odourless all the time
- Fresh, clean and odourless some of the time
- Rarely fresh, clean, and/or odourless
- Unaware of the air quality
- Rarely, stale, dusty and/or smelly
- Stale, dusty, and/or smelly some of the time
- Very stale, dusty, and/or smelly all of the time

3 - To what impact has any workplace and/or external noise affected your performance today? *Select one answer.*

- Significant –ve impact had to take action or move to a quieter location
- Major -ve impact had to take action
- Minor -ve impact slight distraction
- Neutral – no impact perceived
- Minor +ve impact to aid concentration
- Major +ve impact to aid concentration
- Significant +ve impact to aid concentration

For any –ve or +ve impacts please describe briefly!

4 - How would you rate any levels of workplace or personal stress you are experiencing today.
Select one answer.

- Significant –ve affect to my work
- Major some –ve effect to my work
- Minor but no –ve effect to my work
- Neutral – all is fine with me today
- Minor +ve impact it's a necessity of my work
- Major +ve impact I need some stress to perform

- Significant +ve impact I have to stress to perform at my best.

<u>Please advise what type of stress you are suffering:</u>
<u>e.g.</u>

<u>Work task</u>
<u>Workplace – physiological or psychological</u>
<u>Personal – physiological or psychological</u>

5 - So far today, have any of the following building orientated aspects affected your performance?. *Select multiple answers.*

- Inadequate exposure to daylight
- Insufficient workplace lighting levels
- Thermal discomfort (too hot or cold)
- Draughts
- Poor task lighting
- Glare from daylight or artificial lighting
- Odours
- Air Quality
- Noise
- Workplace desk arrangements
- Overall Cleanliness
-

6 - Did you feel specifically tired or fatigued at any particular times during today? *Select multiple answers.*

- 08:00 – 10:00
- 10:00 – 12:00
- 12:00 – 13:00
- No real awareness of being tired
- 14:00 – 16:00
- 16:00 – 18:00
- All day.

7 - On the following scale how would you rate the overall cleanliness of your desk workplace area today?. *Select one answer.*

- Exceptionally clean & tidy
- Very clean & tidy
- Somewhat clean & tidy
- Neutral - no comment
- Somewhat dirty and un-tidy
- Very dirty & untidy
- Exceptionally dirty & untidy

8 - What is your opinion of the adequacy of natural daylight entering the space today?. *Select one answer.*

- No daylight available – full artificial lighting
- Very poor - depressing
- Poor – needs more
- No comment
- Good – would prefer more
- Very Good – just right
- Too much daylight – no control

9 - Using the accompanying scale do you believe the installed artificial lighting has affected your performance today? *Select one answer.*

- Significant -ve impacts my work task
- Major –ve impact to my work task
- Minor –ve impact to my work task
- Allows me to undertake work task adequately
- Minor +ve impact to my work task
- Major +ve impact to my work task
- Significant +ve impact to my work task

What impacts have you suffered today/

10 - How would you rate the overall workplace arrangement to help you feel satisfied and productive today? *Select one answer.*

- Extremely poor
- Very poor
- Poor
- Adequate
- Good
- Very Good
- Excellent

11 - Perceived indoor air quality is a very subjective topic across many building occupants, what is your own perception of the internal conditioned air provided by the buildings air-conditioning system today? *Select one answer.*

- Extremely poor quality
- Very poor quality
- Poor quality
- Adequate

- Good quality
- Very Good quality
- Excellent quality

12 - Considering we all spend approximately 75% of our conscious time at work during the week, how would you rate your overall feeling of well-being today compared to spending the same amount of time relaxing at home or on vacation. *Select one answer*.

- Excellent - workplace environment makes me feel completely satisfied
- Very Good – workplace helps me feel satisfied
- Good – workplace satisfies some of the time
- No Comment
- Poor – workplace doesn't satisfy at any time
- Very Poor - workplace has a detrimental effect on my well-being
- Extremely Poor – workplace has a significant effect on my well-being

13 - At which time today do you believe your performance reached its maximum potential? *Select multiple answers.*

- 08:00 – 09:00
- 09:00 – 10:00
- 10:00 – 11:00
- 11:00 – 12:00
- 12:00 – 13:00
- 13:00 – 14:00
- 14:00 – 15:00
- 16:00 – 17:00
- 17:00 – 18:00

14 - Overall how would you rate personal satisfaction of achievement during today? *Select one answer.*

- Excellent – fully satisfied
- Very Good – almost satisfied
- Good – partially satisfied
- Neutral - No Comment
- Poor – partially satisfied
- Very Poor – only partially satisfied
- Exceptional poor – No satisfaction at all

15 - In terms of your personal satisfaction with your workplace today, how would you rate and/or describe the best and worst features of your overall environment. (free text box)

Example:

The lack of natural daylight or external views does not encourage me to feel personally satisfied with my well-being. I have also feeling extremely warm all day and its felt really stuffy.

16 - How would you rate the overall ventilation in your area today in terms of general air movement today? *Select one answer.*

- Excellent – no discernable impact
- Very Good – some sensation but tolerable
- Good – some sensation with minor corrective action
- Neutral – occasional air movement but I can tolerate the nuisance
- Poor – drafty and a distraction
- Very poor – Needed to add additional clothing and take corrective action
- Exceptional poor – too drafty and unable to control corrective action unable to resolve.

17 - In terms of how you feel currently, what would say your ideal thermal comfort factor would be?

- Rather be considerably cooler
- Prefer to be somewhat cooler
- Just a little cooler
- Neutral – thermal comfort has been fine all day
- Just a little warmer
- Prefer to be somewhat warmer
- Rather be considerably warmer

18 - On or around (2.0m) your desk today do you have any of the following operating? *Select multiple answers.*

- Personal desk fan
- Personal desk heater
- Portable air-conditioning unit
- Task light
- Direct air-conditioning control
- Temperature sensor
- Humidity sensor
- Printer
- Photocopier
- Paper Shredder
- Recycling bins

19 – During today do you believe the workplace had any effect on your personal performance or feeling of well-being. *Select one answer.*

- Significant –ve impact
- Major –ve impact
- Minor –ve impact
- Neutral No material –ve or +ve impact
- Minor +ve impact
- Major +ve impact
- Significant +ve impact

20 – Are there any other aspects within your workplace today which have materially affected your overall level of satisfaction, feeling of well-being or performance?.

Example:

Lifts not working, no amenities available, external noise break in, IT system mal-function.

Notes to be read to each interviewee prior to commencing the semi-structured interview.

- This semi-structured interview is part of a research study you have volunteered to participate and to which we thank you for your involvement, and which is being conducted by Gary Middlehurst, an EngD student within the Technologies for Sustainable Built Environments Centre, School of Construction Management and Engineering located at the University of Reading.
-
- This semi-structured interview should only take a maximum of 30-mins, however, should you need to go earlier, we can schedule its completion at another more convenient time to you.

- Your decision to participate in this study is voluntary. You can stop at any time and are not required to complete all of the questions within the interview. Your participation will be kept confidential and your identification will be restricted to your allocated research volunteer No. and which is securely and confidentially administered.
- Your identity and place of employment will <u>not</u> be mentioned within any publications and/or presentations resulting from this survey.
- Undertaking this interview indicates you have agreed to participate in this part of the research study.
- Would you feel confortable if the interview is recorded, you do not need to accept this request, but it would assist in producing the transcript for your review. Any recorded interviews will be deleted on production and agreement of the transcript.
- If you have any questions, problems or concerns about this research or interview, you may contact Prof. Runming Yao – [redacted] *o***r by phone** [redacted] **or** [redacted] details of which are provided with your original research briefing pack.
- A full transcript and results of each interview will be provided by the Research Engineer within 10-days of the interview, should you wish to change or amend any of your responses, the Research Engineer will modify and re-issue for approval within 5-days of your revised comments.
- If you are comfortable to proceed may I continue with the interview – Thank you.

Semi-structured Interview Questions – Volunteer de-brief session.

1. Please can you confirm your secure volunteer No. and organisation

2. Where you working within Thanet Grange last week and for how long where you based within the workplace?.

3. Over the last 25-days has any specific issues affected you overall performance either within the workplace or outside of work and how affective have you been overall in achieving your work task.?

4. During the past 25-days do you believe the external temperature or climate has affected your perceived state of well-being either within the workplace at home.?

5. During the past 25-days the temperature set point of the air-conditioning system has been altered across +/- 3 degrees, did you perceive any discomfort at any time, indeed, would you recognise such temperature excursions.

6. During the past 25-days the humidity set point of the air-conditioning system has been altered across +/- 3 degrees, did you perceive any discomfort at any time, indeed, did you recognise such humidity excursions

7. Over the past 25-days how would you describe the workplace environment using typical Indoor Environmental factors such as lighting inc. day-lighting, air-conditioning; noise; air quality – too stuffy, smelly; general workplace environment, and thermal comfort.

8. Do you have any specific observations to make about the environment within your workplace over the last 25-days.

General Semi-structured Interview Questions – (45-mins duration.)

11. Many organisations invest heavily in providing clean fresh air to the building occupant, would you say you can appreciate or understand this investment and can you tell the difference between the outside air before you arrive at work and the air provided by the HVAC system.

12. In terms of the lighting system installed within your workplace would you say it is of suitable design and quality, and do you believe artificial lighting and day-lighting should be mutually inclusive i.e. designed and controlled together? What benefits do you think this would deliver to you as a building occupant?

13. Thermal Comfort has long been the biggest Helpdesk issue for many organisations, do you believe a solution lies in providing systems with direct occupant control and systems that can learn intelligently.

14. As a building user would you like to see more intelligent building controls being offered to the occupant, if so what would you like to see controlled and through what access would you prefer e.g. IPhone, Tablet; Remote connection; Intelligent sensors embedded on the occupant, or even intelligent manual intervention.

15. Do you think your organisation should adopt a consistent set of standards for the workplace such that it looks and feels the same wherever you are in your organisation?

16. What facets of the workplace do you believe are the most important for occupant satisfaction and well-being?

17. Is noise or vibration a major issue in the workplace reference to distractions, and/or the inability to conduct your work task? Do you have any current noise or vibration issues and if so how have you mitigated those issues?

18. Sick Building Syndrome is a commonly used phrase within the property industry to define a building with poor indoor environmental quality, is this a term you are familiar, and as a building occupant are you able or willing to describe what you believe this term means.

19. Again and as a building occupant, are you familiar with the term Indoor Air Quality. If you were to attempt to describe what this means how would you describe such a term and the salient points in delivering acceptable air quality.

20. In your opinion what are the most important aspects a workplace environment should deliver in satisfying the expectation of the occupant in order to create a general sense of personal well-being and to drive personal performance and/or levels of personal satisfaction. Do you believe your organisation is delivering to these expectations?

We have now reached the end of semi-structured interview questions thank you for your valuable time. Do you have any additional comments to make about this session or the on-going research process?

Our next interview will be in approximately 3-months time are you comfortable in continuing with this valuable leading class research project.

Thank you again your input is invaluable to our research and I will keep you abreast of the research as it proceeds through a quarterly newsletter via e mail.

Additional questionnaire aimed at Professional designers across Architecture and Building Services Engineers – electronic format.

The following research survey questionnaire has been developed to assess and determine specific ranking factors across key Workplace Environmental Factors (WEF), and forms an integrated approach to assessing a Pre-Occupancy Evaluation (POE) of your preferred working environment to develop enhanced building system designs focussed upon achieving optimum occupant performance.

The survey is based upon a single liner A list of questions will now be presented and should take no longer than 10-mins to complete the survey – Thank-you!

Criteria Ranking (Importance) is detailed within a 9-point scaled questionnaire format from which a pair-wise relative importance calculation is conducted between associated factors using a matrices mathematical modelling method developed by Saaty (1980).

9-point scale - 1:equal; 3:moderate; 5:strong; 7:very strong; 9: Extreme

[1] Not at All Important
[2] -
[3] Moderately important
[4] -
[5] Important
[6] -
[7] Very Important
[8] -
[9] Extremely Important

Not at all Important	Moderately Important			Important	Very Important			Extremely Important
1	2	3	4	5	6	7	8	9

Other even integer values are available for selection should you feel un-sure of the difference between adjacent ranking values.

- To begin answering the questions please follow the on screen instructions – Thank-you.

- Please insert your secure Volunteer Number (VN) issued to you directly (insert date) via e-mail into the box!

You will now be asked 10 demographic questions to obtain additional generalistic information about yourself. *None of this data will be shared without your written consent and approval.*

Thank you for agreeing to participate in this survey.

- Please select the most appropriate answer to the following general questions:-

1. What is your gender – ***male; female.***
2. Age – 18-25; 25-30; 35-40; 40-45; 45-50; over 50.
3. Country of Origin – select from drop down menu.
4. Travel time to and from the Workplace - ***<1hr; 1<2hrs; 2<3hrs >3hrs***
5. Approximately have you taken any time off over the last 12-months
    - (1d; 2d; 3d; 4d; 1wk; >1wk; >2wk; >3wk)
6. If Yes to Q5 – please schedule the condition suffered.
    - (Cold/flue; Headaches; Muscular; Bronchial; sore eyes; nausea, other (if other please describe in the text box)
        - Select multiple answers.
7. What is your general overall perceived feeling of Well-being – ***Very Poor; Poor; Good; Very Good; Excellent***
8. Approximately how many hours are spent at your desk weekly – ***select amount of hours.***
9. Does your desk, chair and general environment satisfy your workplace expectations – ***Yes or No.***
    a. (If No please briefly describe the issues in the free text box.)
10. How long have you worked for your organisation. ***Insert years***
11. Approximately how long do you spend in a workplace type environment each day. – ***select amount of hours.***
12. Approximately how long do spend each day working at a desk mounted P.C - ***select amount of hours.***
13. What is your desk location within the building – Floor level Basement – Level 1;2;3;4;5;6;7;8;9 or 10 – East + (N or S) – West + (N or S) – North - South elevation.
14. On average how much time in hours do you spend in the following areas of the building – Meeting/AV Rooms; Training Room; Breakout areas; Photocopy areas; Kitchenette; Circulation areas; Canteen/Restaurant; Gym; Outside; other.
15. Personally how safe do you feel when working within the buidling – ***very unsafe; unsafe; neutral; safe; very safe.***
16. How easy do you find travelling around the building – Vertically; Horizontally – very difficult; difficult; Neutral; easy; very easy
17. Do you have direct personal control over your HVAC system.
18. Do you have direct personal control over the lighting system.
19. Do you have direct control over daylight i.e. blinds
20. Is your workplace ICT provision sufficient for your task.

Using the Saaty ranking scale of importance [1-9], how important do you consider the following workplace factors are, in helping you to perform at your best within your workplace environment:-

Lighting Quality (LQ):

- Appropriate types of internal artificial Lighting
- Contributory external day-light
- Increased task lighting at your point of work
- Mood lighting to create a focused environment
- Mood lighting to create a subtle ambiance while I work.
- Reduction or elimination of direct or reflective glare
- Adequate levels of illumination at your workspace
- Colour rendering derived from artificial lighting
- The elimination of lamp flicker or stroboscopic effect
- An appropriate type of lighting design for the workspace.
- Different lighting designs in different areas of the building to create different sensory responses.
- Direct Personal control of the lighting in my immediate workplace.
- The lighting to automatically recognise my presence and adjust to my personal requirements.

Indoor Air Quality (IAQ):

- Fresh odourless air within my workspace.
- Fresh fragranced air within my workspace.
- Particulate reduction throughout the building.
- Particulate reduction air within my workspace.
- Minimum levels of CO_2 within my workspace.
- Treated air to control micro-biological contamination between workplace environments and occupants.
- Removal of harmful outdoor chemical contaminants e.g. NOx; CO
- Removal of non-harmful contaminants e.g. Allergens - pollen

Thermal Quality (TQ):

- Controlled thermal environment to prescribed industry standards
- Input to the design of the thermal environment, system types, their controls and preferred location of system components.
- Direct personalised control within my immediate workspace area.
- Ability to directly control Heating & Cooling set-point values within my immediate workspace area.
- Ability to control Humidity set-point values within my immediate workspace area.
- The building's HVAC system to recognise my presence and adjust to my pre-set personalised preferred thermal environment.
- The buidling's HVAC system to recognise my presence and respond to my real-time physiological thermal state and adjust automatically to my preferred thermal environment.

Ventilation Quality (VQ)

- Sufficient volumes of supply and extract air to avoid Sick Building Syndrome (SBS).
- Workplace flow rates so as to cause draughts.
- A sensation of air-flow to achieve a Cooling feeling.
- Ability to control the ventilation supply air-flow rate set-point values within my immediate workspace area.
- Ability to control the ventilation extract air-flow rate set-point values within my immediate workspace area.
- The building's ventilation system to recognise my presence and adjust to my pre-set personalised preferred environment.
- The building's ventilation system to recognise my presence and respond to my real-time physiological thermal state and adjust automatically to my preferred thermal environment.
- The ventilation system to be an integral pat of the HVAC system.
- Adequate ventilation rates to allow you not to feel lethargic.
- Ventilation system to allow you to increase the designed flow rates to satisfy real-time occupant requirements.
- Mixed mode ventilation systems in meeting occupant expectations.

Noise Quality (NM)

- The use of suitable materials within the workplace to provide attenuation and reduce reverberation.
- The design of HVAC systems to provide minimal intrusion to the workplace occupants.
- The design of different workspaces to segregate different noise levels.
- Noise abatement and mitigation to satisfy specific personal requirements.
- An awareness of the differences between internal and building external generated noise.

Workplace Quality (WQ)

- Ease of accessibility into the building from the street level.
- The image of the workplace in meeting occupant expectations.
- The overall look, feel and colour of the space in meeting occupant expectations.
- The design and layout of the workplace in promoting a more effective and efficient working environment.
- The buildings flexibility to allow for future workplace and business change.
- Internal spaces and rooms are large enough for their purpose.
- The overall quality, comfort and style of the workplace furniture.
- The finish and durability of the finishes to enable the workplace to function and remain in a Good condition.
- Design of appropriate ICT systems to alleviate desktop components at the work-desk.
- Sufficient power & data outlets at each work-desk.

- Adequate social and amenity spaces.
- Ease and efficiency of horizontal and vertical building transportation systems.
- HVAC and Building services as a major aspect of workplace design

Appendix – B

PROJECT /ACTIVITY RISK ASSESSMENT FORM (RA2)

Ref. No.

Guidance on completing this form can be found in *University Safety Guide 4 – Guide to Health & Safety Risk Assessments*, available from the H&S website A to Z (go to R).

School / Dept / Unit	**School of Construction Management & Engineering (SCME)** **Technologies for Sustainable Built Environments (TSBE)**
	A: Identifying workplace hazards and existing controls
1. Brief summary of work activity or project assessed	**The work activity is associated with the installtion of 4No. 1.9m metal environmental monitoring poles (evp's) designed and manufactured using 41mm metal galvanised Unistrut channel with various environmental sensors mounted to the channel and at various heights. Following an initial trial at 135 Bishopsgate the evp's are relocated to alternative site being provided by 5plus Architects located at the Hive Building in Manchester, where they will be securly and mechnaically mounted (vertically) to selected desk pedestals or adjacent filing cabinets. Upon fitting the evp's. the environmental monitoring devices will be re-commissioned and set in operation for a 4-week period which will require regular visits to the site to download the aquired data, and to mainatin the equipmemt. Photographic representations are included within the accompnaying e mail It is anticipated that the RE will attend the each Friday during the monitoring period.**
2. List significant hazards	**Area Health & Safety Risk Assessment attached ref. GM/5pA/FR/200615 detailing 10 Low level and managed risks.** **1; 2; 3: 8: 4: 5; 6; 7; 8; 9: & 10.**
3. Relevant University or local guidelines or standards	The works will be undertaken in compliance with the following: SCME - Area Health & Safety Code - Oct 2010 Issue 2. TSBE Helath & Safety Guide 5plus Architects Ltd Helath & Safety Guidelines & Policy documents All relevant UK HSE Guidance documents & Regulations.
4. List who might be exposed to the hazards *(e.g. staff, students, visitors, consider numbers at risk)*	**Research Engineer** **Other students and Supervisors- assisting minimal number <2** **5plus Architects Ltd staff and/or contractors - number <10** **Visitors - N/A**
5. How might they be harmed? *(type of injury or health problem that might result)*	**Trip hazard during installtion; manual handling - muscular injury; head injury - working beloiw desks; hand tool injury - cuts and/or bruises. eye injury.**

6. List control measures in place to reduce risks *Assess whether these controls are adequate, actually used in practice and regularly checked, where appropriate.*	**All electrical equipment will be Portable Appliance Tested and verified where relevant - all hand tools will be battery powered; all monitoring equipment will be battery powered; Trip hazards will be surveyed and mitigated prior, during post the installtion works; apporpiate manual handling tools and devices will be used and 2 man rule will apply; Appropriate hand, eye and head PPE will be worn during all stages of the works. All tools will be fit for purpose and tested and inmspected during the period. Annual PAT testing will not be required. 5plus Architects and UoR RAMS approval process will be utilsied to assess and manage all known risks at site level, workls will not be allowed to proceed until the RAMS is approved and a Permit to Work is released by 5plus Architects. . Attenadnce by 5plus Architects will assit during the works to form a 2-man rule. All affected volunteers adjacent the environmantal monitoring poles will be consulted pre and post installation to incorporate any concerns or comments. All scheduled risks, hazzards and mitigation are detailed upon the attached Area Health & Safety Risk Assessment Form**

B: Assessing the level of risk and further action needed

7.1 How severe is any injury or health effect likely to be?	**Tick one box** (**S** =score given in brackets)	**Minor** ☒ (1)	**Serious** ☐ (2)	**Major** ☐ (3)	**Fatal** ☐ (4)
7.2. How likely is exposure to the hazard?	**Tick one box** (**P** =score given in brackets)	**Very unlikely** ☐ (1)	**Unlikely** ☒ (2)	**Possible** ☐ (3)	**Likely** ☐ (4)
7.3. Calculate the risk score by multiplying the 2 scores in Q7.1 & 7.2	**Risk Score (S x P) =**	**Low** ☒ (1–3)	**Medium** ☐ (4–6)	**High** ☐ (8–9)	**Very High** ☐ (12–16)

8. Immediate further action to be taken to make the situation safe / reduce risk to health	**Action to be taken by whom?**	**Implementation Date**
Full site surveys and inspections coupled with 5plus Architects and UoR RAMS process will mitigate all known risks. RE to work closely with 5plus Architects facilities team and maintenance contractor to maintain a safe working environment. RE to issue full briefing document to 5plus Architects. All equipmemnt is EU compliant and has no deleterious effects to any budiling occupants.	RE	Immediately

9. Further action or additional controls needed to reduce risk as low as reasonably practicable	**Action to be taken by whom?**	**Implementation Date**
All risks have been reduced as far as reasonable & practicable.		

Name of Assessor (please print)	**Gary Middlehurst - RE** **UoR Student No. 16026087**	
Signature of Assessor		**Date:20/06/16**
Signature of Head of Dept/School/Unit		**Date:**

10. Date for Review (maximum 12 months from date of assessment)	**every 3-months**

Appendix – C

TSBE Technologies for Sustainable Built Environments — University of Reading

Rating Scale								
Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

	Question - *Within the modern workplace how would you personally rank the importance of.....*	1. Michelle Agha-Hossein 2. Sarah Birchall 3. Colin Pearson 4. Jo Harris 5. Reginald Brown					6. Mark Roper 7. Ian Wallis 8. Peter Tse BSRIA				Comments/Notes/Key words
		Respondents (x8 + [A] Calculated Average)									
		Please insert a ranking of importance score ranging between 1-9 (as above)									
	Respondee	1	2	3	4	5	6	7	8	A	
	Environmental Quality Factors	9	9	8	9	9	8	9	9	8	
-	**Lighting Quality**	8	9	7	8	7	9	8	9	8	Overall how would you rate lighting quality
1	....appropriate types of internal artificial Lighting	4	8	8	7	9	9	5	7	7	lamp colour; aesthetics; contrasting; up/down lighting
2	...contributory external day-light	9	8	8	7	9	7	7	9	8	energy saving; stimulation; circadian rhythm
3	...increased task lighting at your point of work	6	6	4	5	7	6	5	3	5	supplementary to other artificial lighting and daylight;
4	...mood lighting to create a focused environment	6	4	3	4	6	5	4	2	4	concentrate; detail; mentally tuned
5	...mood lighting to create a subtle ambiance while working.	6	5	3	5	5	2	4	2	4	appropriate for the space and task; location; type
6	...reducing or eliminating direct or indirect glare	9	8	9	8	9	7	6	9	8	artificial lighting; daylight; reflective glare
7	...adequate levels of illumination within the workspace	9	8	9	8	8	8	7	9	8	task based; vertical; horizontal
8	...colour rendering derived from artificial lighting	7	6	7	5	8	6	5	8	7	cool (blue) or warm (yellow) lighting colour; appreciation of object colours
9	... eliminating lamp flicker or stroboscopic effect	9	8	9	9	8	9	6	8	8	less prominent now with HF control gear and LED lamps.
10	...an appropriate type of lighting design for the workspace.	7	7	9	9	8	8	3	8	7	effective; interesting; visually acceptable; fit for purpose.
11	...lighting designs in different areas of the building to create different sensory responses.	4	4	7	5	6	3	3	6	5	creative; stimulating; interesting;

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

	Question - ***Within the modern workplace how would you personally rank the importance of.....***	*1. Michelle Agha-Hossein* *2. Sarah Birchall* *3. Colin Pearson* *4. Jo Smith* *5. Reginald Brown*					*6. Mark Roper* *7. Ian Wallis* *8. Peter Tse* BSRIA				**Comments/Notes/Key words**
		Respondents (x8 + [A] Calculated Average) Please insert a ranking of importance score ranging between 1-9 (as above)									
12	...direct personal control of the lighting within the occupants immediate workplace.	6	7	3	5	7	5	7	6	6	manual or remote control
13	...for lighting to automatically recognise occupant presence and adjust to personal requirements.	6	4	7	5	7	4	4	6	5	integrated intelligent software control - phone; BMS;
14	...lighting systems aligned with the occupants circadian rhythm	9	4	5	5	5	3	5	6	5	health & well-being; stimulate during the day; enhanced systems required.
15	...lighting schemes which incorporate integrated daylight and artificial lighting designs.	5	5	8	6	9	4	7	7	6	control systems; façade design
-	**Indoor Air Quality**	7	7	6	7	7	8	8	7	7	Overall how would you rate indoor air quality
16	...fresh odourless air within the workspace.	9	8	9	9	8	8	7	8	8	external infiltration; internal re-circulation
17	...fresh fragranced air within the workspace.	7	2	1	7	6	1	4	4	4	perfume; essence; airstream
18	...particulate reduction and/or elimination throughout the building.	8	6	8	9	7	7	5	7	7	main AHU plant; higher rated primary filters
19	...particulate reduction air within the workspace.	9	4	9	9	7	7	5	7	7	secondary filters; terminal units; on-floor AHU
20	...minimum levels of CO_2 within the workspace.	9	7	7	9	9	6	8	8	8	background 400pp; 1000ppm; normal; excessive 1500-5000ppm; SBS; health
21	...treated air to control micro-biological contamination between workplace environments and occupants.	8	5	6	8	6	5	4	5	6	ionisation of particles; bespoke systems; virus; improve health
22	...removal of harmful outdoor chemical contaminants e.g. NOx; CO	9	9	8	9	7	4	8	8	8	higher levels of primary & secondary filtration

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

	Question - ***Within the modern workplace how would you personally rank the importance of.....***	*1. Michelle Agha-Hossein*	*2. Sarah Birchall*	*3. Colin Pearson*	*4. Jo Smith*	*5. Reginald Brown*	*6. Mark Roper*	*7. Ian Wallis*	*8. Peter Tse*	BSRIA	**Comments/Notes/Key words**
		Respondents (x8 + [A] Calculated Average) Please insert a ranking of importance score ranging between 1-9 (as above)									
23	...removal of non-harmful contaminants e.g. Allergens - pollen	8	7	8	6	7	6	7	7	7	higher levels of primary & secondary filtration
-	**Thermal Quality**	9	9	9	8	9	8	9	9	9	How would you rate thermal quality
24	...controlled thermal environment to prescribed industry standards	6	8	9	7	8	8	5	7	7	CIBSE; ASHRAE; BSRIA guidance
25	...occupants contributing to the design of the thermal environment, system types, their controls and preferred location of system components.	8	8	6	3	7	3	8	8	6	Pre-occupancy survey responses; AC; NV; Mixed mode
26	...direct personalised control within the immediate workspace area.	7	7	5	3	6	6	8	5	6	manual or remote
27	...being able to directly control Heating & Cooling set-point values within the immediate workspace area.	7	7	5	8	6	5	7	4	6	manual; remote; intelligent; automatically
28	...being able to control Humidity set-point values within the immediate workspace area.	6	7	3	3	5	3	6	4	5	manual or remote
29	...the building's HVAC system to recognise my presence and adjust to my pre-set personalised preferred thermal environment.	6	4	5	6	5	2	4	5	5	intelligent; integrated; ICT; technology
30	...the building's HVAC system to recognise occupant presence and respond to my real-time physiological thermal state.	5	4	7	6	5	3	5	5	5	wearable sensory response; integrated to BMS; intelligent
31	...the building being able to adjust automatically to the occupants preferred thermal environment.	4	4	5	6	6	4	5	5	5	sensory response; integrated intelligent control strategies
32	...the building and indoor thermal performance linked to a discrete ventilation strategy.	6	4	8	3	8	7	4	8	6	mixed mode; NV; AC; dynamic response; energy performance

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

	Question - ***Within the modern workplace how would you personally rank the importance of.....***	*1. Michelle Agha-Hossein 2. Sarah Birchall 3. Colin Pearson 4. Jo Smith 5. Reginald Brown 6. Mark Roper 7. Ian Wallis 8. Peter Tse* BSRIA; Respondents (x8 + [A] Calculated Average); Please insert a ranking of importance score ranging between 1-9 (as above)									Comments/Notes/Key words
33	...having a range of temperatures to satisfy all occupant preferences.	6	7	7	8	6	6	7	6	7	demographic response; gender; control philosophy; complex management
34	...having a range of thermal criteria for different indoor environments.	8	7	8	8	8	7	6	6	7	energy; performance; recognition of different spaces and user needs;
-	**Ventilation Quality**	7	6	7	7	6	7	7	7	7	How would you rate Ventilation quality
35	...sufficient volumes of supply and extract air to avoid Sick Building Syndrome (SBS).	8	9	7	9	9	8	6	8	8	People; health; flow rates; condensation; smells; odours
36	...workplace air flow rates so as not to cause annoying draughts.	8	8	7	9	8	8	5	7	8	diffuser location; type; fan speed; airflow design
37	...creating a sensation of air-flow to achieve a cooling feeling.	6	6	4	6	7	5	5	3	5	human senses; psychologically pleasing; satisfying feeling
38	....having the ability to control the ventilation **supply** air-flow rate within the immediate workspace area.	6	7	4	7	8	6	7	6	6	manual; remote; cooling; heating
39	...of having the ability to control the ventilation **extract** air-flow rate within the immediate workspace area.	4	7	4	7	8	4	6	6	6	manual; remote; CO2 control; cooling;
40	...the building's ventilation system to recognise occupant presence and adjust to the occupants pre-set personalised preferred environment.	7	4	7	6	6	3	4	8	6	intelligent; integrated; ICT; technology
41	...the building's ventilation system to recognise occupant presence and respond to the occupants real-time physiological thermal state.	7	3	6	6	5	3	4	7	5	wearable sensory response; integrated to BMS; intelligent
42	...to adjust automatically to the occupants preferred thermal ventilation environment.	7	4	5	6	7	3	4	7	5	intelligent; integrated; ICT; technology
43	...the ventilation system to be an integral pat of the HVAC system.	5	7	9	8	8	6	5	9	7	AC; NV; Mixed mode; central & distributed control

TSBE — Technologies for Sustainable Built Environments

University of Reading

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

Respondents: 1. Michelle Agha-Hossein; 2. Sarah Birchall; 3. Colin Pearson; 4. Jo Smith; 5. Reginald Brown; 6. Mark Roper; 7. Ian Wallis; 8. Peter Tse — BSRIA

Respondents (x8 + [A] Calculated Average)

Please insert a ranking of importance score ranging between 1-9 (as above)

	Question - *Within the modern workplace how would you personally rank the importance of.....*	1	2	3	4	5	6	7	8	A	Comments/Notes/Key words
44	...adequate ventilation rates to allow occupants not to feel lethargic.	8	9	9	8	8	8	7	9	8	CO2 issues; freshness; stimulating; odourless
45	...the ventilation system to allow occupants to increase the designed flow rates to satisfy real-time occupant requirements.	7	6	4	6	7	6	6	8	6	dynamic; intelligent; integrated; knowledge based
46	...selecting the most appropriate ventilation system to maximise occupant performance or productivity.	7	7	7	9	7	6	6	8	7	NV; AC; Mixed mode; task orientated
-	**Noise Quality**	7	6	8	7	7	8	7	8	7	How would you rate noise quality
47	....using suitable materials within the workplace to provide attenuation and reduce reverberation.	9	8	9	9	8	7	6	8	8	fabrics; furnishings; spatial design; finishes
48	....designing HVAC systems to provide minimal intrusion to the workplace occupants.	7	8	9	9	7	7	4	8	7	Specification of plant; standards design brief
49	...designing different workspaces to segregate different noise levels.	8	7	5	9	8	5	5	8	7	break-out; focussed work; quiet time; social space
50	..noise abatement and mitigation to satisfy specific personal requirements.	7	7	5	6	7	4	4	8	6	furniture; layout; barriers; acoustic pods
51	...background noise within the workplace	6	5	4	8	8	4	5	8	6	white noise; music; intelligent counter noise
52	...occupant awareness towards the differences between internal and building external generated noise.	7	6	5	6	7	3	4	8	6	knowledge transfer; awareness; intelligent mitigation
53	...understanding the clients workplace noise levels to avoid unnecessary distractions.	6	7	6	8	8	5	6	8	7	active measurements; benchmark; knowledge transfer; timing to avoid noisy periods

TSBE — Technologies for Sustainable Built Environments   University of Reading

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

Respondents: *1. Michelle Agha-Hossein; 2. Sarah Birchall; 3. Colin Pearson; 4. Jo Smith; 5. Reginald Brown; 6. Mark Roper; 7. Ian Wallis; 8. Peter Tse* — BSRIA

	Question - *Within the modern workplace how would you personally rank the importance of.....*	Respondents (x8 + [A] Calculated Average) — Please insert a ranking of importance score ranging between 1-9 (as above)									Comments/Notes/Key Words
	Respondee	1	2	3	4	5	6	7	8	A	
	Occupant Performance Factors	6	7	7	7	6	7	8	7	7	
1	...designing workplaces with occupant well-being as a fundamental deliverable	8	7	9	9	8	7	7	8	8	standard; principle; client brief; expected
2	...appreciating the psychological impacts imposed by the workplace	7	7	8	9	7	7	5	8	7	PreOE; POE; awareness; design; feedback
3	...empirically understanding the physiological impacts of the workplace	7	6	8	9	6	5	6	6	7	heart rate; skin temperature; metabolic rate; blood oxygen; metabolic rate; galvanic skin response; breathing rate
4	...designing healthy workplace environments	7	8	9	9	8	6	5	8	8	compliance; minimise absenteeism; productive employees
5	...achieving every known IEQ comfort factor	6	5	4	7	6	2	5	5	5	utopia; expensive; compromise; reality
6	...maximising occupant productivity and/or performance	7	7	7	8	8	6	6	7	7	basic; organisational; achievable; measurable
7	...designing to meet recommended medical breathing rates within the workplace	7	7	7	9	5	7	8	7	7	necessity; possibility; need; awareness; reality
8	...integrating occupant skin temperature to inform the BMS and HVAC system	6	4	1	3	5	3	3	3	4	heat map; responsive; accuracy; integration; effectiveness
9	...understanding galvanic skin response (GSR) to inform the BMS and HVAC system	5	3	1	6	5	2	3	2	3	stress; levels; awareness; connection; how; what; when; why
10	...an awareness heart rate response imposed by the workplace	6	3	3	3	5	3	5	6	4	too hot; too cold; affect; reason; why; rationale
11	...incorporating blood oxygen levels into the HVAC ventilation strategy	6	3	1	5	3	1	5	3	3	benefit; awareness; relevance; connecting
12	...calculating and aggregating occupant metabolic rates to inform the BMS	5	3	4	4	4	3	4	6	4	energy expended; exchange rate; time; HVAC response

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

	Question - ***Within the modern workplace how would you personally rank the importance of.....***	*1. Michelle Agha-Hossein 2. Sarah Birchall 3. Colin Pearson 4. Jo Smith 5. Reginald Brown*	*6. Mark Roper 7. Ian Wallis 8. Peter Tse* BSRIA								**Comments/Notes/Key words**
		Respondents (x8 + [A] Calculated Average)									
		Please insert a ranking of importance score ranging between 1-9 (as above)									
		1	2	3	4	5	6	7	8	9	
13	...understanding occupant activity levels within the workplace to avoid sedentary existence	6	5	6	9	7	4	4	8	6	health & well-being; stimulate; movement; activity
14	...meeting individual occupant physiological responses within defined benchmarks	4	6	5	6	8	4	5	6	6	expectations; satisfaction; values; occupant awareness
15	...stimulating the physiological activity of the occupant within the workplace	5	7	5	7	9	5	5	7	6	environment; local; impact; positive; negative; good; bad
16	...using wearable sensory equipment to integrate individual physiological responses	6	4	5	1	3	2	3	2	3	intelligent; integrated; responsive; live; measures
17	...trending and integrating occupant physiological responses within an intelligent and responses workplace	5	4	4	2	4	3	3	6	4	BMS; knowledge; energy; benchmarks; efficiency; gap
18	...using physiological response as a primary design deliverable, method and/or assessment tool	5	5	3	2	5	4	3	4	4	standard; data; knowledge; improve; availability
19	...conducting pre-occupancy surveys to assess physiological needs	7	8	6	6	7	4	5	4	6	PreOE; POE; awareness; design; feedback; benchmark
20	...conducting specific health & well-being POE surveys to assess success	7	8	6	8	8	6	6	7	7	PreOE; POE; awareness; design; feedback; benchmark
21	...managing expectations and awareness of workplace and occupant impact & responses	7	8	7	8	8	8	7	7	8	rationale; presentation; need; feedback; improvement; knowledge base
22	...benchmarking occupant physiological performance - individually and as a work-group	7	8	7	3	7	6	4	7	6	energy; saving; awareness; change; development; knowledge
23	...assessing physiological exchange with the workplace environment to inform the BMS and HVAC systems	5	7	5	3	5	5	4	6	5	heat; transfer; energy; efficiency; response; adjust; automatic
24	...the BMS to transmit data and knowledge to inform the occupant of their physiological performance against benchmarks and building data.	5	6	7	1	5	3	5	6	5	graphical; impact; change; work practice; affect; stimulate response

Rating Scale

Not at all Important		Moderately Important		Important		Very Important		Extremely Important
1	2	3	4	5	6	7	8	9

Question -
Within the modern workplace how would you personally rank the importance of.....

1. Michelle Agha-Hossein
2. Sarah Birchall
3. Colin Pearson
4. Jo Smith
5. Reginald Brown
6. Mark Roper
7. Ian Wallis
8. Peter Tse

BSRIA

Respondents (x8 + [A] Calculated Average)

Please insert a ranking of importance score ranging between 1-9 (as above)

	Respondee	1	2	3	4	5	6	7	8	A	Comments/Notes/Key words
	Workplace Quality Factors - *Overall Rating*	7	8	7	8	8	8	7	8	8	
1	...ease of accessibility into the building from the street level.	7	5	9	9	8	5	7	3	7	ramps; handrails; functional door ways; security
2	...the image of the workplace in meeting occupant expectations.	7	6	9	9	7	6	4	5	7	smart; clean; tidy; professional; statement;
3	...the overall look, feel and colour of the space in meeting occupant expectations.	7	6	9	8	6	4	4	6	6	stimulating; pleasing; intelligent; encouraging; satisfying
4	...sufficient work space so as not to feel over-crowded.	8	7	9	8	7	7	7	7	8	density; layout; stress; disturbance
5	...the design and layout of the workplace in promoting a more effective and efficient working environment.	8	7	8	8	8	6	6	8	7	collaboration; social; flexible; inspiring
6	...the buildings flexibility to allow for future workplace and business change.	7	6	7	7	5	5	9	8	7	adaptability; growth; development; value
7	....internal spaces and rooms which are large enough for their purpose.	7	7	7	8	7	7	6	8	7	net lettable; efficiency; cost; sufficient
8	...the overall quality, comfort and style of the workplace furniture.	7	6	7	8	5	4	6	8	6	ergonomics; comfort; ease of use
9	...the finish and durability of the finishes to enable the workplace to function and remain in a good condition.	7	7	7	8	5	5	7	8	7	cleanliness; impressions; functional;
10	...appropriate ICT systems to alleviate desktop components at the work-desk.	7	7	8	6	4	5	6	8	6	flexibility; intelligent; functional; ease of use; integrated
11	...sufficient power & data outlets at each work-desk.	8	9	9	8	5	6	7	8	8	cable management; accommodate ICT; ease of use

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1	2	3	4	5	6	7	8	9

	Question - ***Within the modern workplace how would you personally rank the importance of.....***	*1. Michelle Agha-Hossein* *2. Sarah Birchall* *3. Colin Pearson* *4. Jo Smith* *5. Reginald Brown*					*6. Mark Roper* *7. Ian Wallis* *8. Peter Tse* BSRIA				**Comments/Notes/Key words**
		Respondents (x8 + [A] Calculated Average)									
		Please insert a ranking of importance score ranging between 1-9 (as above)									
12	...adequate social and amenity spaces.	6	5	3	8	5	3	4	8	5	interactive; social; communicative; flexible; amenities; functional
13	...ease and efficiency of horizontal and vertical building transportation systems.	7	6	5	8	8	4	3	7	6	ease of access; reliability; functional; expedient;
14	...HVAC and building services as a major aspect of workplace design	7	7	7	3	7	4	7	8	6	efficient; effective; comfort orientated; flexible; controllable
15	...external vistas and visible outside space.	5	7	5	4	7	3	5	8	6	façade design; glazing; obstructions; lines of sight; window design
16	...occupant amenities e.g. catering; health, break-out areas.	6	7	7	6	5	5	7	8	6	flexible; perception; adequate; facilities; time
17	...understanding the work task in relation to designing the workplace environment	7	5	8	8	7	6	6	8	7	client engagement; POE; interviews; monitoring;
18	...creating a workplace which promotes current environmental awareness and impacts	6	6	7	8	5	4	4	8	6	corporate statement; alignment; occupant preferences; compliance
19	...providing facilities e.g. toilets areas which are reliable and easily repaired.	9	8	9	9	8	6	9	8	8	maintenance; cost effective; longevity; value; reliability; availability
20	...having the appropriate capex budget to deliver an appropriate level of workplace design	7	4	9	9	7	6	5	7	7	engagement; aware; value; functional; maximise
21	...participating in agreeing the long-term opex budget to deliver life cycle value	6	4	7	9	7	7	6	8	7	understanding the effects of design; inclusive; hand-over; maintenance; replacement
22	...building location in meeting the demands of the business and its employees	7	6	9	9	6	5	6	8	7	client brief; location; area; cost; relative; image
23	...workplace as a reflection and transition between home and other occupied spaces	6	6	5	3	6	2	4	8	5	segregate; incorporate; liveable; different; differences
24	...transition from outside the building to desk as easily as possible	6	6	4	6	4	3	5	4	5	efficient; security; ease; functional;

Appendix – D

21. Many organisations invest heavily in providing clean fresh air to the building occupant, would you say you can appreciate or understand this investment and can you tell the difference between the outside air before you arrive at work and the air provided by the HVAC system.

"in my opinion it never comes on to the agenda in terms of clean fresh air it seems to be accepted as a given. I have worked on 5-6 recent office environments and all of them have been developed as naturally ventilated buildings for one reason or another, but generally because we articulate the virtues of adopting natural ventilation. This is not just from a cost saving advantage, but also as a sensible approach to meeting business needs and occupant comfort. As a practice we promote NV buildings, but we don't look to enhance the fresh air using mixed mode or increased filtration equipment. We do however recognise within the design of The Hive building that is where we are today, that the naturally ventilated design does have some issues, which we have discovered since occupying the space. These issues relate to how the BMS interacts with the needs of the space to achieve fresh air particularly in the mornings when the air can be quite stuffy, and when we need to be able to provide fresh air as quickly as possible to improve the conditions. Previous buildings we have been involved with have been refurbished buildings and not new designs, but The Hive has allowed us to model better our approach as a case study I suppose. One of the key issues we have learned through adopting our approach, is that there doesn't seem to be any real intelligence within the BMS to anticipate the environmental conditions, so we have to manually react to the conditions and ask the engineers to adjust the dampers in the full height ventilation grilles. Alternatively and usually in addition, we open the windows manually to assist the situation. The lesson learned for us is to look at how we get the BMS to become more intelligent and predict the environment!."

22. In terms of the lighting system installed within your workplace would you say it is of suitable design and quality, and do you believe artificial lighting and day-lighting should be mutually inclusive i.e. designed and controlled together? What benefits do you think this would deliver to you as a building occupant?

"Natural day-light is certainly better than artificial lighting in my opinion, but there is always a need for task lighting particularly as you age I feel. Difficulties I generally see are were we go from looking at an ICT screen then looking to paper on your desk, and the levels of contrast you experience between the two. I am not sure there are any lighting systems that could cater for this issue, as the ergonomics of the environment will dictate the ability to provide light on the work desk. Day-light provides a more indirect level of illumination that is a naturally occurring relationship we are use to both at work and outside work. Our subjective response to day-light is embedded in our natural existence so why don't we take more advantage of this fact. The lighting within The Hive building is not day-light linked, but it is dimmable. I would like to see some day-lighting linking particularly here in Manchester, particularly when we see a lot of contrasting and changing light levels due to passing clouds throughout the day. It

would be useful to achieve a more uniformed and constant lighting level so you are not distracted from large changes in levels. I would like to see more personal control of lighting system specific to the user area, but not sure how we achieve this in application yet. The windows here are approximately 35% of the façade area, with a typical office façade being 50% glazed, and we see this as a design consideration when we are modelling the building efficiency, but we do not necessarily consider this as a lighting design issue at such an early stage of the design process. The windows are designed for better day-light penetration within The Hive and we were specific to maximise day-light entering the space, conscious we needed to meet building regulations and best performance of the façade from a thermal perspective."

23. Thermal Comfort has long been the biggest Helpdesk issue for many organisations, do you believe a solution lies in providing systems with direct occupant control and systems that can learn intelligently.

"The trouble I think we have is that we have working environments that are different every day. The workforce to day is agile and therefore not all desks are full everyday or even at specific times of the day. The related issue here, is that we generally design to a standard which is 100% occupied so is not a sustainable or efficient approach. This agility factor we are now experiencing is affecting all aspects of buildings not just thermal comfort. It is very difficult for todays BMS systems to learn intelligently and handle the discrete differences of the environment on a day to day basis, they simply are not configured or their sensors arranged in a way that can measure or assess and then react in a predictive manner. Knowing how many people are in the office is important, but with work practices changing, it is difficult to know what the environment will actually be at any given time. In terms of thermal comfort and from my experience people generally do not complain when it's cold, but they generally complain when it's too hot. Having said that and here in The Hive we do get complaints from people who sit too near the vents, as it can get quite drafty and cold. Those in the middle of the office seem to be warmer, and some of those who sit near the windows say they get too cold occasionally, but we don't see any major affect to performance, we just deal with the situation and move on. Personally I think it's about air movement, rather than temperature, which is why we believe naturally ventilated space work better than engineered forced cooled or heated buildings. Once it gets too hot, then we should look to adapt to the environment instead of asking the building to react though some form of BMS, but we do need to remain conscious of the heat gain profile as we design the workplace. Façades should respond to orientation and environment but be passive, because as we include and attach more systems the more things that can go wrong and fail which then subsequently can create even bigger issues. What we want is intelligent passive buildings rather than intelligent active buildings. The ventilation grilles we have here at The Hive are certainly not intelligent enough, they are either open or closed. In my retrospective view, they should be controlled, and be able to adjust air flow, and to have control via temperature, humidity and air quality – but this adds complexity and cost."

24. As a building user would you like to see more intelligent building controls being offered to the occupant, if so what would you like to see controlled and through what access would you prefer e.g. IPhone, Tablet;

Remote connection; Intelligent sensors embedded on the occupant, or even intelligent manual intervention.

"15-yrs ago I designed a building were the lighting system could be controlled from the desk telephone, but what we have here at The Hive is a phone App that controls the music system. In affect it works along similar to the principles of controlling the lights from your desk phone principles so it provides occupants with a form of direct interface to create a response to the environmental requirements. Today, and if we were going to provide a system interface, then I think it needs to be phone or ICT App based, this is what people are becoming more familiar with and seem to want. There will however in my opinion be an issue with people adjacency and some level of conflict, but we just need to educate people to communicate and to manage themselves within the workplace. It's not just about building physics to solve the environmental problem, it's about people learning how to interact with their local environment. What we need in my opinion s something akin to the luxury car where you set the parameters you like and tend to feel comfortable, the you have an interface were you can adjust if required. Designers need to focus on what's important and not to over complicate the options you have to control things. When a building is occupied people should respond and integrate with the building and the building and the user should control the environment. When the building is empty then the building systems should simply react to achieve a prescribed set condition and then close everything down to save energy. Buildings need to learn when the building is just a building."

25. Do you think your organisation should adopt a consistent set of standards for the workplace such that it looks and feels the same wherever you are in your organisation?

"Yes I do, and I think it's even more important when you have multiple offices where you could have different assets and systems that need to interact. There needs be some consistency, but some personalisation particularly when you move between offices. Something which is familiar is always reassuring as you feel more comfortable at home within the space more quickly. London is certainly different to Manchester and we have different requirements in making these types of decisions, for instance, the type of buildings we occupy, their age, condition and arrangement. But economies of scale are a sensible option in the real world. Meeting the needs of the occupant by making the workplaces similar to work within, operate and enjoy is a key factor we adopt when designing buildings or workplaces. We do however need to be careful when defining a standard. Europe and the UK has such differing demographics so within the UK its fine, once you move internationally other demographic issues come into play, so we need to be careful when we standardise. For example, we design in the UK for temperatures on a holistic basis, where as we should have regional standards and become smarter to designing for external ambient rather than internal conditions. The difference in external temperatures across the UK can be extreme, yet we still design to a common standard. We seem to be using the wrong criteria in my opinion setting internal temperatures as the standard. If we are going to be sustainable then we need to set our designs based upon external temperatures with an association towards what the occupant in a specific regions can realistically adapt to or tolerate."

26. What facets of the workplace do you believe are the most important for occupant satisfaction and well-being?

“Two key things exist in this area, but there is a third, the look and feel of a space, is it well maintained and is it somewhere that you like and feel proud to work in for instance. Brand association is also important. IEQ factors are very important, but it’s in the last 10-yrs anecdotally, that I see people are tending not to complain about their environment, but complain more about data and IT issues. Does my IT work properly and is it reliable and resilient to allow me to do my job effectively and efficiently. If IT worked 100% of the time, then the workplace would become in my opinion a secondary issue, as the user would adapt to maintaining the focussed task they were employed to conduct. It’s about de-stressing the work task rather than spending overtly on the workplace. Plants are banned from 5+ as an example despite what people may say that it’s a great way introducing the outside to stimulate productivity. They hey ruin the look and feel of the space and become a distraction in my opinion. We provide facilities that allow people to conduct their work well, professionally and simply, we prefer to promote better working practices and engagement rather than over burden the workplace with clutter. Culture is very important, it influences well-being subjectively, and it’s also about effective leadership. Don’t get me wrong, the workplace is important, a poor environment reflects the way organisations treat their employees, but the design needs to be representative of occupant needs and desires rather than just a designers thoughts.”

27. Is noise or vibration a major issue in the workplace reference to distractions, and/or the inability to conduct your work task? Do you have any current noise or vibration issues and if so how have you mitigated those issues?

“Noise and vibration non specifically, but what is noise. From my university days, noise is defined by unwanted sound which in this office is the music being played too loud or too many people on the phone when you are trying to have a private conversation. In an open plan office noise seems to be the biggest issue we suffer from but we only have a finite amount of space. We do have issues with workplace noise as we are hi-density space, so it can be distracting at times. We have and encourage background music in order to provide a common language and culture, and to keep staff within a group rather disappearing into their own ear phones and cultural worlds. External noise does transfer into the space, but I see that as entertainment and a necessary distraction to remain connected with the outside world, a bit like having a window and view. The way we have set out the space to create a quiet area you can escape to I think works well, and we have positioned the meeting rooms towards the quieter side road side rather one of the main arteries of Manchester. This allows us to minimise the need for excessive acoustic treatment even with the hard surfaces throughout the office.”

28. Sick Building Syndrome is a commonly used phrase within the property industry to define a building with poor indoor environmental quality, is this a term you are familiar, and as a building occupant are you able or willing to describe what you believe this term means.

"I don't really know what it means if I'm honest, know one has never really explained a definition. As an example, when you go to a US shopping mall and its cooled to within an inch of its cooling capacity it just seems awkwardly wrong and not somewhere you would want to spend a great deal of time. Conversely this is the opposite of what the shop owners want so we have miss-matched the needs of the occupant to the shop keeper straight away. A classic example is an office I worked on some years ago were the air was re-circulated around the office. Basically if someone had a cold then everyone got the cold. Similarly if there is a bug in our office then the natural ventilation tends to dilute the spread of infection and we haven't see too much incidence of absenteeism, however in winter when all the windows are closed we do get a lot of colds being transferred. Lighting I suppose is another issue where the colour rendering has improved as has glare control. We as a practice prefer to see more day-light orientated lighting designs providing it's done correctly. People are getting smarter and aware of their health, sitting has become the new smoking our sedentary existence is now putting our heath at risk. The body is conditioned to adapt to harsh environments, and perhaps we have become too soft in our prescribed environments. Perhaps therefore, we need to encourage and enforce changes throughout the day in order to stimulate the body rather than have a constant consistent environment. Smell and odours seem to me to be the biggest issues particularly from the kitchen areas and they do cause a distraction, but is this again about creating a community within the office – possibly."

29. Again and as a building occupant, are you familiar with the term Indoor Air Quality. If you were to attempt to describe what this means how would you describe such a term and the salient points in delivering acceptable air quality.

"You come into a room and it feels stuffy so you open a window, that's generally how I view IAQ. I think we need to consider IAQ, but should a building actually be moderating you from everything around us, or should it be keeping you connected to the outside space?. Perhaps in London and hi density areas we do need protection from poor air quality, but it carries a cost we need to be aware of as designers. IAQ is important for sure, but we need to understand the external and internal environment separately before we accept any holistic solution."

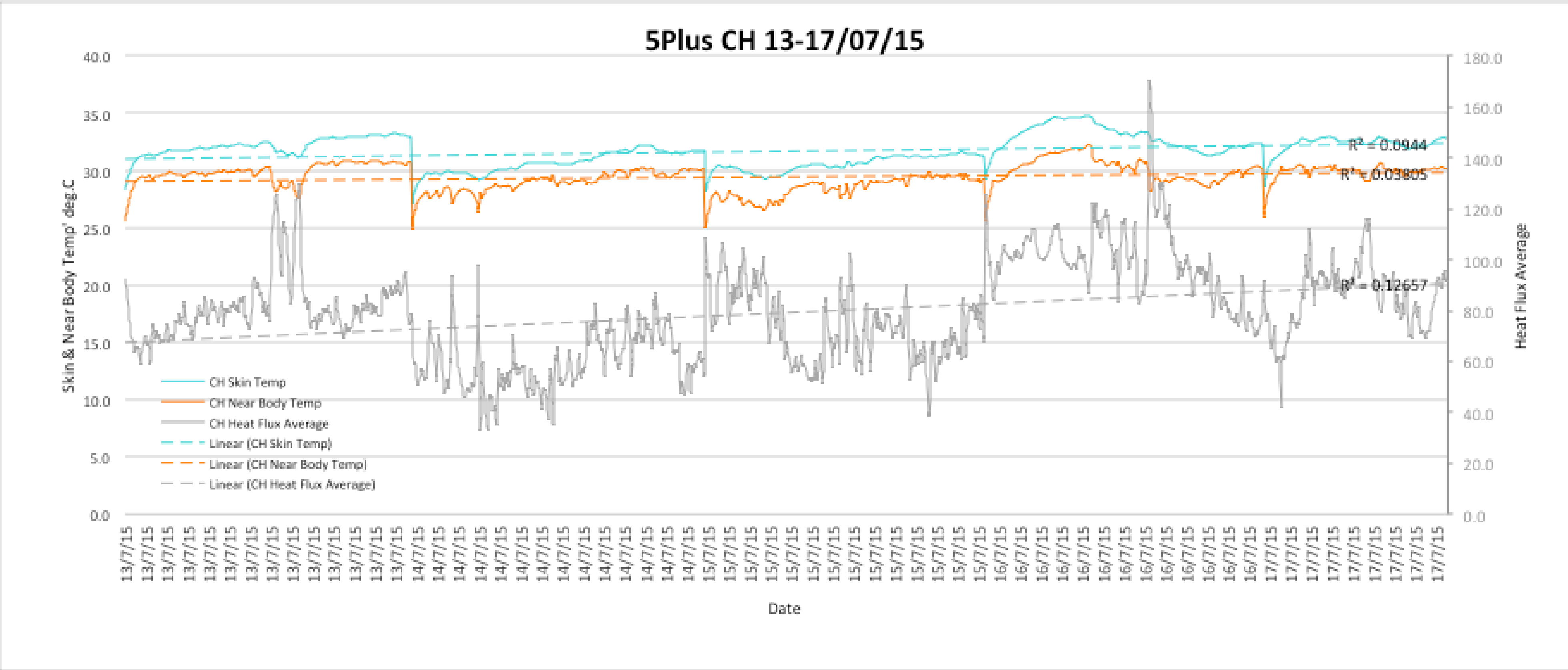
30. In your opinion what are the most important aspects a workplace environment should deliver in satisfying the expectation of the occupant in order to create a general sense of personal well-being and to drive personal performance and/or levels of personal satisfaction. Do you believe your organisation is delivering to these expectations?

"Good IT matching the brand value of the business and the occupant is essential, the world is moving so fast the work task has become the focal issue. IT and the workplace should be flexible, adaptable it should be economic and sustainable. I didn't mention building services did I, that in my opinion comes from good sustainable design, the building services should be a given deliverable. Its more than just services its about people."

We have now reached the end of semi-structured interview questions thank you for your valuable time. Do you have any additional comments to make about this session or the on-going research process?

Thank you again your input is invaluable to our research and I will keep you abreast of the research as it proceeds through a quarterly newsletter via e-mail.

Appendix – E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Skin & Near Body Temp' deg.C
Heat Flux Average
Date
R^2 = 0.0944
R^2 = 0.03805
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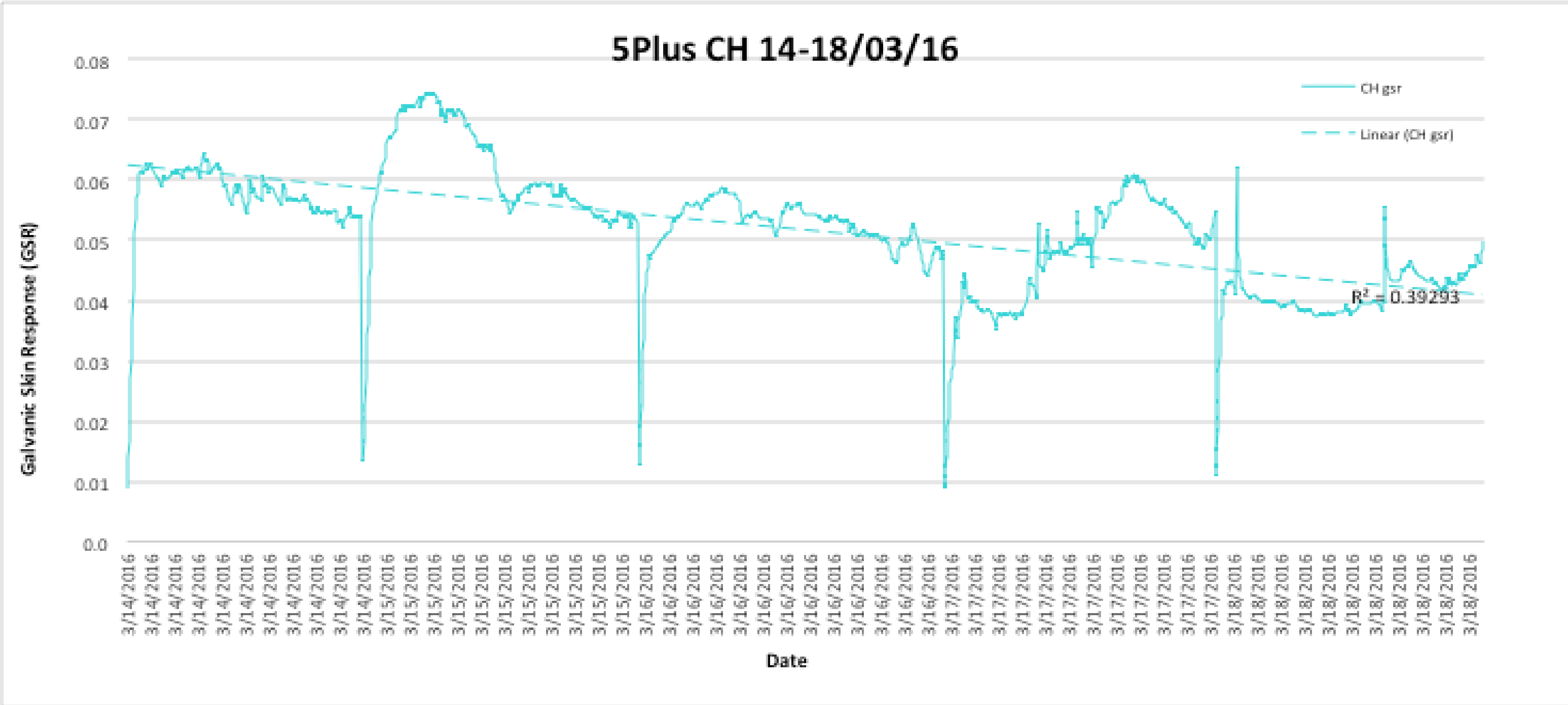
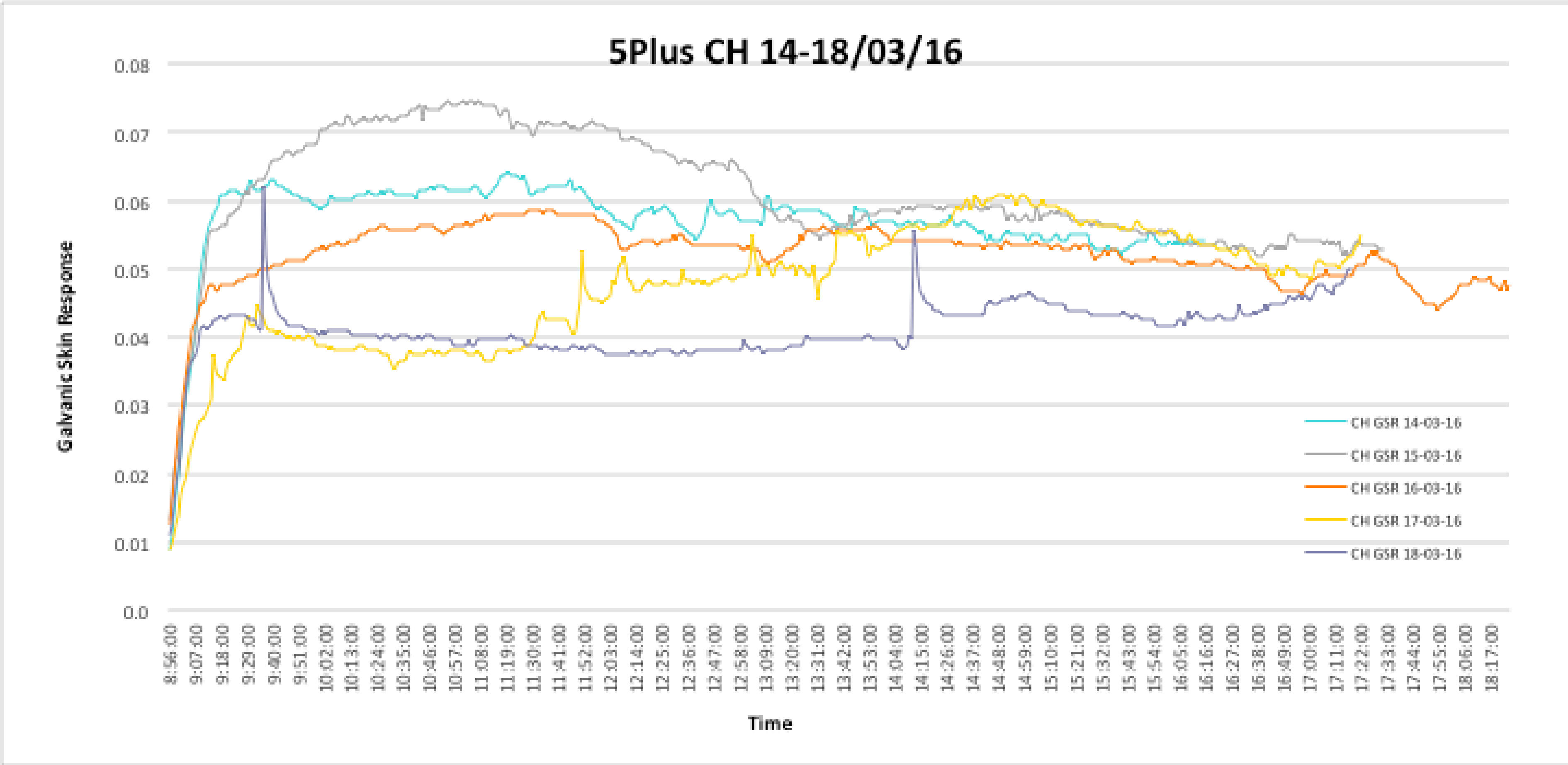
Linear (CH Heat Flux Average)



5Plus CH 14-18/03/16
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.0
Galvanic Skin Response (GSR)
CH gsr
Linear (CH gsr)
R² = 0.39293
3/14/2016
3/15/2016
3/16/2016
3/17/2016
3/18/2016
Date


5Plus CH 14-18/03/16
Galvanic Skin Response
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.0
Time
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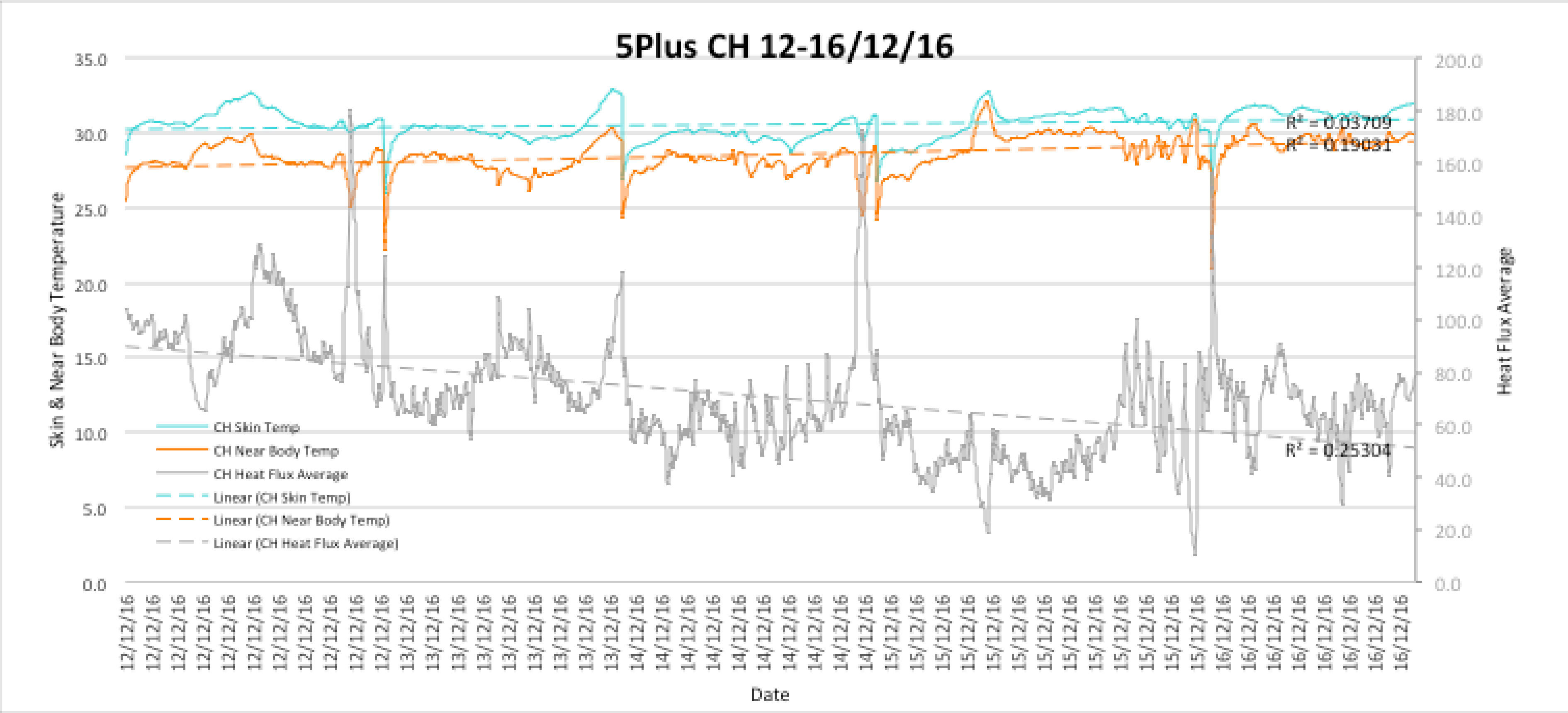
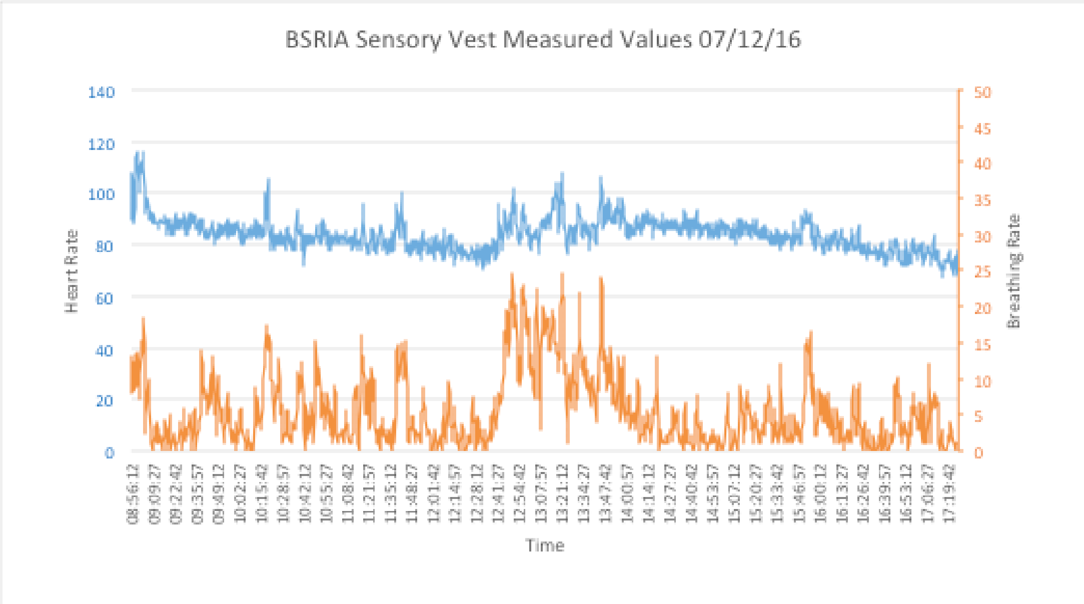
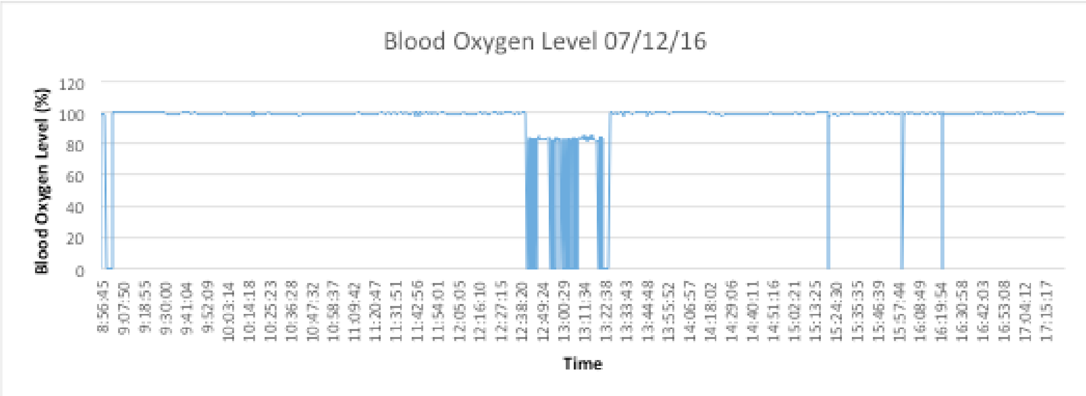
CH GSR 15-03-16
CH GSR 16-03-16
CH GSR 17-03-16
CH GSR 18-03-16



5Plus CH 12-16/12/16
Skin & Near Body Temperature
Heat Flux Average
Date
CH Skin Temp
CH Near Body Temp
CH Heat Flux Average
Linear (CH Skin Temp)
Linear (CH Near Body Temp)
Linear (CH Heat Flux Average)
R² = 0.03709
R² = 0.19031
R² = 0.25304


BSRIA Sensory Vest Measured Values 07/12/16
Heart Rate
Breathing Rate
Time


Blood Oxygen Level 07/12/16
Blood Oxygen Level (%)
Time